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DOSES TO ROAD TRANSPORT WORKERS FROM RADIOACTIVE MATERIALS

by

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ABSTRACT

Each year approximately 750,000 packages of radioactive materials are shipped throughout Canada. Regulatory controls on these shipments are designed to keep radiation doses received by transport workers well within acceptable limits. Since many of these workers are not monitored for radiation exposure, however, little factual information has been available in Canada to support theoretical estimates. A study to document actual radiation doses received by a select group of transport workers that is actively involved in the shipment of radioactive materials, was carried out in 1987 and 1988. This study involved the monitoring of 31 candidates from nine transport companies from across the country that handle medical isotopes, industrial isotopes, uranium fuel cycle materials and associated radioactive wastes. Each of the candidates (consisting of drivers, dock workers, sorters and supervisors) was issued personal thermoluminescent dosimeter (TLD) badges that were worn each work day during the six-month monitoring period. Some of the candidates were also issued "cab" or "area" dosimeters that were left in the cabs of vehicles or in work areas so that the dose received in these areas could be differentiated from total personal exposure.

During the monitoring program, the candidates filled out reporting sheets at the end of each working day to document information such as the quantity of materials handled, handling times and vehicle size. This information and the dosimetry data were used in the development of correlations between materials handled and doses reported so that doses for others handling similar materials could be estimated.

Based on the results of the study, it was learned that while most of the transport workers receive doses that are at or near background levels, others (particularly those handling medical isotopes) are exposed to levels of radiation that may result in their receiving doses above the 5 mSv per annum limit set for members of the general public. On the basis of the six-month data, however, maximum annual doses for participants in the study were found to be less than 14 mSv.

Résumé

Chaque année, environ 750 000 colis de matières radioactives sont expédiés à travers le Canada. Ces envois font l'objet de contrôles réglementaires afin de s'assurer que les doses de radiations auxquelles sont exposés les transporteurs sont conformes aux limites permises. Cependant, étant donné qu'un grand nombre de ces travailleurs ne sont soumis à aucun contrôle concernant les radiations, on dispose au Canada de peu de renseignements permettant d'étayer des estimations théoriques. Pour combler ce manque, on a réalisé, en 1987 et 1988, une étude en vue d'établir les doses de radiations reçues par un groupe cible de transporteurs de matières radioactives, très actifs dans le domaine. Cette étude consistait à suivre 31 candidats, choisis dans neuf compagnies dans tout le Canada, et transportant des isotopes médicaux et industriels, des matières dues au cycle de combustion de l'uranium et des déchets radioactifs connexes. On donna à chacun d'eux (conducteurs, travailleurs de quais, trieurs et surveillants) des dosimètres individuels à thermoluminescence, qu'ils devaient porter tous les jours de travail durant la période de contrôle de six mois. Quelques-uns des candidats reçurent également des dosimètres de «véhicules» ou de «zones», qui furent laissés dans les véhicules ou dans les lieux de travail, afin de différencier les doses reçues dans ces endroits de celles dues à l'exposition totale.

Au cours du programme, les candidats ont rempli des feuilles de relevés à la fin de chaque journée de travail sur les quantités de matières transportées, les temps de manutention et la dimension des véhicules. Ces informations, plus les données des dosimètres, ont servi à établir des corrélations entre les doses indiquées et les matières manipulées, afin d'évaluer les doses reçues par d'autres transporteurs de matières similaires.

Les résultats de cette étude ont révélé que la plupart des transporteurs reçoivent des doses équivalant aux niveaux normaux ou proches de ceux-ci, et que d'autres (plus particulièrement les transporteurs d'isotopes médicaux) sont exposés à des radiations pouvant dépasser la limite annuelle de 5 mSv, établie pour le public en général. Cependant, grâce au données recueillies pendant six mois, on a pu déterminer que les doses maximales annuelles reçues par les participants sont inférieures à 14 mSv.

DISCLAIMER

The Atomic Energy Control Board and Transport Canada are not responsible for the accuracy of the statements made or opinions expressed in this publication and the Board, Transport Canada and the authors assume no liability with respect to any damage or loss incurred as a result of the use made of the information contained in this publication.

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1.0 INTRODUCTION

Each year there are approximately 750,000 packages of radioactive materials shipped throughout Canada by transport and courier companies other than Canada Post. These packages contain such materials as medical and industrial isotopes, uranium fuel cycle products as well as associated radioactive wastes. These materials are either imported into the country or they are produced at facilities that are licensed by the Atomic Energy Control Board (AECB), a crown corporation that has been set up to regulate the use and development of nuclear energy in Canada. The packages are generally shipped to other facilities (such as refineries, medical facilities and testing laboratories) that are also licensed by the AECB. Since the people handling radioactive materials at these licensed facilities are likely to receive occupational doses of ionizing radiation that are greater than the annual limit set for members of the general public, they are classified as "Atomic Radiation Workers" (ARWs). While on the job, these people wear small devices known as dosimeters to monitor the "dose" or amount of ionizing radiation to which they have been exposed as they handle or work in the vicinity of the radioactive materials. The doses received by these individuals are reported in units called millisieverts (mSv). A maximum annual whole body dose limit of 50 mSv has been set for the ARWs. For members of the general public, however, the annual limit is reduced to 5 mSv, one-tenth of the ARW limit.

Regulations concerning the handling, storage and packaging of radioactive materials in Canada are enforced by the AECB. These regulations dictate the maximum acceptable limits of radiation that may be emitted from the surfaces of the various types of packages that are used to ship radioactive materials. Since acceptable levels of radiation emissions are permitted, handlers of these packages may be exposed to some radiation. The dose received depends upon the amount of the radiation reaching the handler and the handling period.

While some of the packages of radioactive materials shipped throughout Canada are transported by people who are routinely monitored for exposure to radiation, many are shipped by privately-owned companies with employees who are not monitored. Although regulatory controls on these shipments are designed to keep the radiation dose to these transport workers to within acceptable limits, for those not monitored, it has not been known in the past if their annual whole body doses exceed the 5-mSv limit that would require their being classified as ARWs. To obtain this information, a study was carried out in 1987 and 1988 to document actual doses received by a select group of transport workers involved in the handling of various types of radioactive materials.

This report documents the various tasks that were undertaken to complete this study. In Section 2, the selection of companies to participate in the study is discussed. Site visits to these participating companies are addressed in Section 3. The criteria used in selecting candidates for monitoring are presented in Section 4. Details of the monitoring program are laid out in Section 5. The data collected during the study is discussed in general terms in Section 6. The factual data collected is summarized in Section 7. Analyses of this data are given in Section 8. Conclusions are drawn in Section 9. Recommendations for further work are put forth in Section 10.

Schematics to illustrate the shipping routes and vehicles employed by the participating companies are presented in Appendix A. A brief description of the dosimeter badges used in the study and a general discussion on thermoluminescent dosimetry are included in Appendix B. Copies of the reporting forms used by the monitored candidates to document materials handled, are provided in Appendix C. The data used in the development of correlations between dose reported and materials handled, along with some of these correlations are given in Appendix D.

2.0 SELECTION OF PARTICIPATING COMPANIES

The initial selection of transport companies to participate in the study was undertaken by the AECB. Licensees of the AECB who are major shippers of radioactive materials were asked to identify their principal road transport carriers and types of materials shipped. From this information, 24 transport companies were identified. From these, a preliminary list of 10 companies was developed using the following selection criteria:

- -estimated volume of business
- -principal regions of operation
- -type of radioactive materials carried
- -number of licensees served
- -probable distances travelled
- -other unique features relevant to the study.

While the initial selection of companies was somewhat subjective, the suitability of each was assessed during the early stages of the study.

Each of these 10 companies was contacted by the AECB and, with the exception of one, all agreed to participate in the study. A list of the nine participating companies together with the name of a contact person from each was then forwarded to MacLaren Engineers Inc.

3.0 INITIAL SITE VISITS

At the outset of the study, each of the nine transport companies on the preliminary list was contacted by telephone to determine the type and frequency of their shipments of radioactive materials, and to set up site visits so that observations of actual shipments could be arranged. During these conversations it was learned that some of the companies handle radioactive materials at more than one depot. It was also learned during the early stages of the study, that two of the selected companies were unsuitable for the program. One no longer handled radioactive materials, and the other had no regular drivers on the routes involving the handling of radioactive materials. When these carriers were deleted from the study and replaced with two additional transport companies whose shipping methods matched the parameters of the study, the final list of participants consisted of nine firms.

After determining shipping procedures and quantities with the company contacts from each of these firms, site visits to the appropriate depots were scheduled. During these site visits, observations of actual shipments of radioactive materials were made and typical gamma radiation measurements were taken with scintillometers (portable instruments that detect gamma radiation) in specific areas of the depot, within the transport vehicles, and on the radioactive packages themselves. Based on these observations and measurements, it was apparent that at some facilities, employees other than drivers were being exposed to ionizing radiation. These included loading dock workers and sorters who were involved in loading and unloading vehicles and in sorting packages for various destinations. Also included were supervisors who, while overseeing the handling operations, were sufficiently close to radioactive materials to receive some exposure. These observations, as well as general shipping procedures, were discussed with the company contacts. Tentative suggestions for candidates to participate in the monitoring program were also put forth.

After the site visits had been completed, schematic diagrams that illustrate the various shipping routes and transport vehicles were produced for each company. These schematics also included the results of the gamma measurements taken during the site visits before the actual monitoring began, and formal suggestions for candidates to be monitored. The schematics were then forwarded to the company contact at each facility who was asked to comment on the accuracy of the schematics and the selection of candidates. These comments were then used to make the necessary corrections or additions to the schematics. Revised copies of these schematics are presented as Figures A-1 to A-9 in appendix A of this report. Indicated on these figures are the points of origin and destination, the various vehicle types and the gamma activities measured by scintillometer during the site visits. These activities, in units of μSv/hr (1 μSv = 10^{-3} mSv) were measured in the cabs and sleeper units of the vehicles. "Contact" activities were those recorded with the instrument in contact with the surfaces that the handler could physically touch. Depending upon the type of material shipped, these surfaces included the sides of trailers, shipping containers and the packages themselves.

4.0 SELECTION OF MONITORING CANDIDATES

After the initial site visits had been completed and the schematics corrected, the selection of candidates for the monitoring program was finalized. Although a minimum of one candidate was selected from each depot at which radioactive materials are handled on a regular or semi-regular basis, as many as 10 candidates were selected from some facilities. Altogether, 31 primary candidates who regularly handle or work near radioactive materials, were chosen from the participating companies. These individuals included the following:

- truck drivers on scheduled routes who handle the materials
- truck drivers who do not handle the materials
- depot workers who load and unload vehicles
- personnel who sort packages according to destination
- depot supervisors.

In addition to these primary candidates, at some of the facilities other personnel who were involved with handling of radioactive materials on an irregular basis, were included as secondary candidates. A total of nine of these secondary candidates were included in the study.

5.0 MONITORING PROGRAM

5.1 General

A major objective of the study was to determine actual doses of radiation received by the candidates selected to participate in the monitoring program. To determine these doses, the candidates were issued thermoluminescent dosimeter (TLD) badges to wear on their person while engaged in the handling of radioactive materials. These dosimeters, provided by the Bureau of Radiation and Medical Devices (BRMD) of the Department of National Health and Welfare, are widely used in Canada to determine occupational doses of ionizing radiation. (Further details on the use of TLD's are found in Appendix B of this report.)

The candidates were monitored for a six-month period that began at the first of October 1987 and ended at the end of March 1988. During that period, the TLD badges were worn each day during the normal work shift. At the end of the shift, the badges were removed and placed in places of limited access where they remained until the following work period. As is standard practice in the nuclear industry, these badges were worn for a period of three months and then they were returned to the company contacts who issued replacements. Pink labels were attached to these badges to identify the wearer and the monitoring period. In addition to these badges, the candidates were issued a second badge that was also worn during the work shift. These badges, however, were only worn for one month before they were exchanged for new ones. Yellow labels were used on the one-month badges to identify the wearer and the month during which they were worn. There were a number of reasons for requesting that the candidates wear two badges. First, with a duplicate badge, the risk of losing data should a particular badge be damaged or lost, was reduced. Second, duplicate badges provided additional data points for comparing doses received with materials handled. Third, anomalous results for individual badges

could be substantiated or refuted with duplicate data. Fourth, if one-month badge results had indicated that some of the participants were receiving very large doses in a short period of time, changes in working conditions could have been incorporated early in the monitoring program without waiting until the three-month data became available.

Some of the candidates participating in the monitoring program not only drive vehicles containing radioactive materials, they also carry the packages against their bodies. This is particularly true for the couriers who handle short-lived medical isotopes that are used in hospitals and laboratories. Based on gamma readings taken with the scintillometers at some of the depots, it is apparent that the doses received during the carrying of these packages are generally considerably higher those received while transporting them in a vehicle. This reduction in exposure is due to the physical separation between the driver and the load. To determine the dose received while driving, some candidates were issued a third badge that was attached to the sun visor of the cab of the vehicle during the normal work shift. This badge was given a green label to identify the candidate and the three-month period for which it was used. Thus the candidate's total personal dose for three months was determined from the badge with the pink label, and the dose received while driving was indicated by the green-labelled badge. The difference between the two approximated the dose received while carrying the packages to and from the vehicle.

As indicated previously, some of the candidates involved in the study handle radioactive materials on a regular basis, but they do not drive vehicles as part of their daily activities. These candidates were issued additional badges that were attached to the walls or structural members of the depot in the general locations where radioactive materials are stored during the normal work shift. A green label was attached to these badges to identify their monitoring locations within the depot and the three-month periods for which they were used. These badges were used to determine the doses received by individuals who

work at the depot in the vicinity of the radioactive materials but who do not actually handle them.

Additional badges were also issued to the company contact to act as control dosimeters. These badges were left in a place of limited access (generally in the location where the personal dosimeters were stored during off hours) for a period of three months. They were given a blue label that identified the storage location and the monitoring period.

5.2 Reporting Requirements

A second major objective of the study was to correlate doses received with the types and quantities of materials handled, so that these correlations could be used to estimate the doses likely to be received by others in the industry. To document the quantity of materials handled by the participants, each person was asked to fill in a reporting sheet each working day. Due to the variety of materials handled and differences in handling methods, separate sheets were prepared for those involved in the shipping of each of the following types of radioactive materials:

- medical isotopes
- industrial isotopes
- uranium concentrate
- exclusive use containers (for Co-60, UF_6, UO_3 and wastes)

Copies of these reporting sheets are found in Appendix C of this report. As indicated, each sheet documented the materials handled by the candidates for one month. The data contained on the reporting sheets includes the following:

- the number of trips taken each day
- daily travelling time
- loading and unloading times

- vehicle size
- the type and quantity of materials handled
- the position of the materials within the vehicle
- whether the containers were full or empty
- deviations from normal routine
- relevant comments

5.3 Presentations

Prior to the commencement of the monitoring program, each facility was revisited and discussions were held with the individual candidates so that they were apprised of the goals and requirements of the study. They were given a short presentation on the subject of radioactivity, during which, the effects of separation and shielding were demonstrated. The badging system was described and the reporting requirements were discussed in detail. The candidates were informed that the program was being carried out on a voluntary basis and that their co-operation was appreciated since it would contribute to the overall success of the study. Most candidates expressed a sincere desire to participate as they were genuinely interested in determining their own doses. As a small token of appreciation, the participants were issued a cap to indicate that they were involved in the transportation study.

5.4 Site Revisits

During the first month of the monitoring phase of the study, each facility was revisited to observe compliance with the requirements of the study, and to address any difficulties or questions that arose. The data provided on the reporting sheets was reviewed and any corrections or modifications were instituted at that time.

6.0 COLLECTION OF DATA

At the end of each month, the candidates submitted their completed reporting sheets and appropriate badges to the company contact who forwarded them to MacLaren Engineers Inc. The reporting sheets were then reviewed to ensure the adequacy of the data and the badges were forwarded to BRMD for analyses. Generally the data and badges were received within an reasonable length of time although some delays were experienced due to the infrequency with which some of the drivers visit their offices.

Of the 286 badges issued to primary participants during the study, 269 or 94% were received. Of the remainder, ten were lost in the mail and seven were lost at the depots where they were being used.

After the badges had been read by BRMD, the results were further analyzed and reviewed in detail before they were forwarded on to MacLaren Engineers Inc. The results were reported in units of millisieverts (mSv) with a stated accuracy of $\pm$ 0.1 mSv. Background exposures were reported as <0.1 mSv.

The dosimetry results and the data documented by the 31 primary participants are summarized in the following section. The information pertaining to the secondary participants has not been included (since these people were not involved in the handling of radioactive materials on a regular basis and their reported doses were generally very low), however, it was reviewed and used to verify the data provided by the primary participants.

7.0 SUMMARY OF DATA COLLECTED

7.1 General

The results of the data collected during the monitoring phase of the study are summarized in four tables by the types of materials handled as follows:

MATERIALS HANDLED	TABLE NO.
Medical Isotopes	7.1
Exclusive Use Containers	7.2
Uranium Concentrate	7.3
Industrial Isotopes	7.4

7.2 Medical Isotopes

Medical isotopes are materials that, because of their relatively short half-lives, are frequently delivered to medical facilities by courier companies. Generally these isotopes are packaged in cardboard boxes labelled to identify the contents and to indicate the levels of radiation being emitted from them.

Packages of these isotopes that emit levels of radiation that do not exceed 5 microsieverts (μSv/hr) at any point on their external surfaces, fall into Category I and are identified by a white label containing a trefoil (radiation) symbol and the word "RADIOACTIVE" followed by the Roman Numeral I coloured red.

Packages that emit levels of radiation between 5 and 500 μSv/hr at any point on their external surfaces are included in Category II and are identified with a yellow label and the Roman Numeral II in red. These labels also contain a square in which the transport index (a measure of the radiation detected at a distance of one metre from the package in

units of μSv/hr divided by 10) is indicated. The maximum transport index for a Category II package is 1.0.

Category III packages are identified with a yellow label and the Roman Numeral III in red. These packages must not emit radiation at a rate greater than 2000 μSv/hr at any point on their external surfaces and have a transport index that does not exceed 10.

By observing the colour and numbers on the labels, the handlers of these packages have some indication of the radiation levels associated with them.

The results of the data collected by the candidates who handle these types of packages are summarized on Table 7.1.

The first column on this table shows the designations that were used to identify the candidates. The job descriptions for the candidates are given in the second column. The candidates that physically carry radioactive packages as part of their daily routine are identified in column 3. Vehicle types and sizes are indicated in column 4. The times spent by the candidates in their vehicles or depots are shown in columns 5 to 8. The "O/J" heading at the top of column 5 indicates the times (in hours) that the candidates spent in the vehicle or depot during the month of October (shown on the first line) and January (shown on the second line). November and February times are given in column 6 under the heading "N/F" and December and March times are given in column 7 under the heading "D/M". Three-month total times are shown in column 8.

Similarly, loading and unloading times are given in columns 9 to 12. Three-month totals are shown in column 13.

The number of Category I packages handled during the monitoring period are given in columns 13 to 15 and are totaled in column 16.

TABLE 7.1 - - - SUMMARY OF DATA RECEIVED FOR CANDIDATES HANDLING MEDICAL ISOTOPES (MI) - - -

DES'N	JOB	CARRY VEHICLE		IN VEHICLE/DEPOT(hr)				LOADING/UNLOADING(hr)				#1 PACKAGES				#2 PACKAGES				#3 PACKAGES				REPORTED DOSE (mSv)					CAB	AREA 1	AREA 2
				O/J	D/F	D/M	TOTAL	O/J	D/F	D/M	TOTAL	O/J	D/F	D/M	TOTAL	O/J	D/F	D/M	TOTAL	O/J	D/F	D/M	TOTAL	O/J	D/P	D/M	O-D/J-M	OCT-MAR			
MI-1	HELPER	YES	5-TON	15.2	16.7	13.4	45.3	7.0	9.0	9.6	25.6	65	37	18	100	321	319	244	886	184	187	144	515	less	1.0	1.0	4.4		0.6	D/A	D/A
				11.5	14.8	19.4	45.7	8.7	9.3	10.2	28.2	29	41	40	112	295	323	359	977	164	191	229	584	1.5	0.8	0.8	2.3	6.7	0.3	D/A	D/A
MI-2	DRIVER	NO	48-FT	10	30	12	60	0.75	1.25	0.5	2.5	0	0	0	0	3	6	2	11	10	15	6	31	less	<.1	<.1	0.4		D/A	D/A	D/A
				18	18	18	54	1.0	1.0	1.0	3.0	0	0	0	0	3	3	3	9	10	10	10	30	<.1	<.1	<.1	<.1	<.5	D/A	D/A	D/A
MI-3	DRIVER	NO	48-FT	70.8	80.5	94.2	245.5	0	0	0	0	65	37	18	100	321	319	244	886	184	187	144	515	less	<.1	<.1	<.1		D/A	D/A	D/A
				132	127	146	405	0	0	0	0	29	41	40	112	295	323	359	977	164	191	229	584	<.1	<.1	0.3	<.1	<.2	D/A	D/A	D/A
MI-4	DRIVER	YES	VAN	24	31.5	9.5	65	2.2	1.0	1.5	5.5	0	0	1	1	9	11	7	29	6	2	2	10	less	<.1	<.1	<.1		0.3	D/A	D/A
				11	6	8.5	25.5	0.5	1.5	1.0	3.0	0	0	0	0	7	1	5	15	2	3	2	7	0.1	<.1	<.1	0.1	<.2	0.2	D/A	D/A
MI-5	DRIVER	YES	VAN	0.5	1.3	0.5	2.3	0.3	0.7	0.3	1.3	0	0	0	0	2	7	3	12	7	10	6	23	less	<.1	<.1	0.1		<.1	D/A	D/A
				1.0	0.8	0.9	2.7	0.6	0.3	0.5	1.4	0	0	0	0	2	2	2	6	6	2	4	12	<.1	<.1	<.1	<.1	<.2	<.1	D/A	D/A
MI-6	DRIVER	YES	5-TON	1.3	1.3	1	3.6	4.8	4.7	3.5	13	60	49	29	138	165	152	85	402	178	155	87	420	less	0.4	0.1	1.3		0.6	D/A	D/A
				1.3	1.3	1.3	3.9	2.3	2.3	2.3	6.9	47	47	37	131	90	113	112	315	131	128	133	392	1.0	0.4	0.4	1.5	2.0	0.2	D/A	D/A
MI-7	SUPER	NO	D/A	168	168	168	504	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	less	<.1	<.1	0.1		D/A	0.2	<.1
				168	168	184	504	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	<.1	<.1	<.1	<.1	<.2	D/A	0.1	<.1
MI-8	SUPER	NO	D/A	168	168	152	488	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	less	<.1	<.1	0.1		D/A	0.1	<.1
				144	168	184	488	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	D/A	<.1	<.1	<.1	<.1	<.2	D/A	<.1	<.1
MI-9	SORTER	YES	D/A	187	220	191	598	D/A	D/A	D/A	D/A	49	75	49	173	354	379	325	1058	172	196	158	526	less	1.0	1.4	4.0		D/A	D/A	D/A
				184	178	184	546	D/A	D/A	D/A	D/A	68	69	72	209	380	352	401	1133	185	193	220	598	2.0	0.8	0.7	2.6	6.6	D/A	D/A	D/A
MI-10	SUPER	SOME	D/A	146	187	113	446	D/A	D/A	D/A	D/A	60	49	30	139	176	172	95	443	191	167	95	453	less	0.6	<.1	2.0		D/A	<.1	<.1
				147	151	152	450	D/A	D/A	D/A	D/A	47	47	37	131	99	118	119	336	139	133	139	411	0.3	0.3	0.1	0.5	2.5	D/A	<.1	<.1
MI-11	DRIVER	YES	LEASE	27.8	26	11.3	65.1	0.6	0.9	0.3	1.8	6	4	1	11	15	12	9	56	1	3	3	7	<.1	<.1	<.1	<.1		<.1	D/A	D/A
				33	51	21	105	0.7	1.1	0.5	2.3	3	6	2	11	25	36	13	72	2	0	3	5	<.1	<.1	<.1	<.1	<.2	0.1	D/A	D/A
MI-12	DRIVER	NO	45-FT	56.5	60	31	155.5	10	12	6	28	4	3	1	8	63	96	28	187	78	44	20	142	<.1	<.1	<.1	0.3		D/A	D/A	D/A
				55	61	58	184	12	12	10	34	2	1	3	6	14	21	41	76	3	0	15	18	<.1	<.1	<.1	<.1	<.0	D/A	D/A	D/A
MI-13	SUPER	NO	D/A	65.5	80	76.5	242	D/A	D/A	D/A	D/A	3	8	6	17	172	186	144	502	220	187	294	701	0.1	<.1	0.1	1.0		D/A	1.2	0.1
				76.5	76	72	224.5	D/A	D/A	D/A	D/A	5	6	7	18	164	208	180	552	176	153	171	500	<.1	<.1	<.1	0.1	1.1	D/A	<.1	0.2
MI-14	SORTER	YES	D/A	76	80	68	224	D/A	D/A	D/A	D/A	3	8	6	17	172	186	144	502	220	187	294	701	1.9	1.6	0.1	2.8		D/A	D/A	D/A
				68	76	72	216	D/A	D/A	D/A	D/A	5	6	7	18	164	208	180	552	176	153	171	500	1.0	<.1	<.1	0.4	3.2	D/A	D/A	D/A

NOTE: D/A = NOT APPLICABLE

The number of Category II packages handled are presented in columns 17 to 20.

The numbers for Category III packages are summarized in columns 21 to 24.

The doses reported for the monthly badges are given in columns 25 to 27. The three-month badge results are shown in column 28. The results of the three-month badges are added together in column 29 under the heading "OCT-MAR".

Doses reported for the cab and area badges are shown in columns 30 to 32.

7.3 Exclusive Use Containers

Some of the candidates involved in the study haul radioactive materials that, because of their levels of radioactivity or the way they are used in industry, are transported in specially designed containers. These containers are dedicated to one type of material and are used exclusively for them. These materials include Co-60, UF_6, UO_3 and some radioactive wastes. The data for the participants who handle these types of containers is summarized in Table 7.2.

In this table, the designations assigned to the candidates are given in the first column.

The materials contained within the exclusive use containers are identified in column 2.

The fact that all of the candidates are drivers of transport vehicles is shown in column 3.

TABLE 7.2 - - - SUMMARY OF DATA RECEIVED FOR CANDIDATES HAULING EXCLUSIVE USE CONTAINERS (EU) - - -

DES'N	MATERIALS	JOB	IN VEHICLE (FULL CONT) O/J	N/F	D/M	TOTAL	IN VEHICLE (EMPTY CONT) O/J	N/F	D/M	TOTAL	# OF FULL CONTAINERS O/J	N/F	D/M	TOTAL	# OF EMPTY CONTAINERS O/J	N/F	D/M	TOTAL	REPORTED DOSE (mSv) O/J	N/F	D/M	O-D/J-M	OCT-MAR
EU-1	UF6	DRIVER	78.3	93.3	80.3	251.8	138.5	138.5	72.5	349.5	24	18	20	62	37	15	6	58	4.5	2.1	0.4	4.0	
			104.5	106.5	134.5	345.5	110.5	127.5	92.0	330.0	26	27	29	82	36	50	30	116	0.3	0.5	0.1	0.9	4.9
EU-2	UF6	DRIVER	40.0	65.0	55.0	160.0	0.0	0.0	0.0	0.0	16	26	22	64	0	0	0	0	<.1	<.1	<.1	0.2	
			70.0	70.0	40.0	180.0	0.0	0.0	40.0	40.0	27	28	16	71	0	0	24	24	0.2	0.1	0.1	0.4	0.6
EU-3	Co-60	DRIVER	15.5	4.0	4.5	24.0	34.0	0.0	7.5	41.5	5	3	3	11	4	0	5	9	0.5	<.1	<.1	<.1	
			3.0	11.0	4.0	18.0	24.0	17.0	18.0	59.0	5	4	2	11	0	3	2	5	<.1	<.1	<.1	<.1	<.2
EU-4	Co-60	DRIVER	12.0	8.0	6.0	26.0	0.0	0.0	3.0	3.0	4	2	4	10	0	0	1	1	0.4	<.1	<.1	<.1	
			8.0	8.0	0.0	16.0	0.0	0.0	0.0	0.0	5	13	0	18	0	0	0	0	<.1	<.1	<.1	<.1	<.2
EU-5	U03	DRIVER	19.0	101.0	112.0	232.0	19.0	101.0	82.5	202.5	6	36	45	87	3	44	39	86	<.1	<.1	<.1	<.1	
			81.5	81.0	61.5	224.0	81.5	81.0	61.5	224.0	33	33	24	90	38	34	24	96	<.1	<.1	0.1	<.1	<.2
EU-6	U03	DRIVER	93.5	143.0	99.0	335.5	93.5	143.0	84.0	320.5	39	51	45	135	40	61	47	148	<.1	<.1	<.1	<.1	
			106.0	105.0	109.0	320.0	106.0	105.0	109.0	320.0	42	42	42	126	51	46	52	149	<.1	<.1	<.1	<.1	<.2
EU-7	U03	DRIVER	103.5	36.0	50.5	190.0	103.5	36.0	50.5	190.0	33	12	21	66	36	15	19	70	<.1	<.1	<.1	<.1	
			99.5	114.5	109.0	323.0	99.5	114.5	109.0	323.0	39	45	42	126	45	51	50	146	<.1	<.1	<.1	0.4	<.5
EU-8	WASTES	DRIVER	63.0	71.0	80.0	214.0	N/A	N/A	N/A	N/A	49	47	49	145	0	0	0	0	<.1	<.1	<.1	0.2	
			67.0	77.0	78.0	222.0	N/A	N/A	N/A	N/A	70	72	83	225	0	0	0	0	0.1	<.1	<.1	0.3	0.5

The times spent in the vehicle each month while hauling full containers are given in columns 4 to 6, and summed in column 7.

The times spent hauling empty containers are given in columns 8 to 11.

The number of full containers hauled during the monitoring period is summarized in columns 12 to 15.

The number of empty containers transported is summarized in columns 16 to 19.

Monthly doses are shown in columns 20 to 22.

The three-month doses are shown in column 23 and totaled in column 24, under the heading "OCT-MAR".

7.4 Uranium Concentrate

Uranium concentrate is another type of radioactive material that was transported by some of the participants during the study period. This is the material produced at uranium mines in the northern regions of Ontario and Saskatchewan. As the ore is processed, the concentrate is recovered in the form of a slurry. This material is then dried and shipped in steel drums to Blind River, Ontario, where it is further refined as an intermediate step in the production of nuclear fuels. A by-product of this refining stage is a liquid material containing some uranium. This material, called raffinate, is taken back to the mines where the residual uranium is extracted. The data for the haulers of these uranium materials is summarized on Table 7.3.

In this table the candidate designations are shown in column 1.

From column 2, it can be seen that most of the participants were drivers who hauled the product in trucks. Participant UC-2, however,

TABLE 7.3 - - - SUMMARY OF DATA RECEIVED FOR CANDIDATES HAULING URANIUM CONCENTRATE (UC) - - -

DES'N	JOB	IN VEHICLE (hr)				LOADING (hr)				# OF DOORS				LOADS OF DOORS				LOADS OF SLURRY				LOADS OF RAFFINATE				DEPOSITED DOSE (mRv)						
		D/J	D/F	D/N	TOTAL	D/J	D/F	D/N	TOTAL	D/J	D/F	D/N	TOTAL	D/J	D/F	D/N	TOTAL	D/J	D/F	D/N	TOTAL	D/J	D/F	D/N	TOTAL	D/J	D/F	D/N	D-D/J-N	OCT-MAR	AREA 1	AREA 2
UC-1	DRIVER	171.5	192.5	101.5	485.5	43.3	68.5	74.0	177.8	N/A	N/A	N/A	N/A	20	25	19	64	22	32	36	90	3	0	2	5	C.1	C.1	C.1	0.3		N/A	N/A
		180.0	174.5	121.5	476.0	81.0	85.0	64.0	230.0	N/A	N/A	N/A	N/A	19	19	17	55	34	33	28	87	2	0	0	2	C.1	C.1	C.1	C.1	C.4	N/A	N/A
UC-2	LOADER	N/A	N/A	N/A	N/A	36.0	41.5	17.0	94.5	1118	1388	520	2938	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.1	C.1	C.1	0.3		0.2	0.2
		N/A	N/A	N/A	N/A	0.0	6.0	13.0	19.0	0	172	352	524	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	C.1	LOST	LOST	0.5	0.0	0.4	0.3
UC-3	DRIVER	116.0	95.5	41.0	252.5	35.0	29.5	20.5	85.0	464	414	169	1047	9	9	4	22	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	C.1	C.1	C.1	C.1		N/A	N/A
		76.5	39.0	84.5	200.0	11.0	5.0	11.0	27.0	365	183	365	913	8	4	8	20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	C.1	C.1	C.1	C.1	C.2	N/A	N/A
UC-4	DRIVER	76.5	90.0	37.5	204.0	13.5	12.5	5.0	31.0	373	420	186	979	8	9	4	21	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	C.1	C.1	C.1	C.1		N/A	N/A
		9.0	52.5	72.5	125.0	0.0	5.5	4.0	9.5	0	276	328	564	0	5	7	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	C.1	C.1	C.1	C.1	C.2	N/A	N/A
UC-5	DRIVER	63.5	39.0	0.0	102.5	0.0	17.0	0.0	17.0	285	186	0	471	6	4	0	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	C.1	C.1	C.1	C.1		N/A	N/A
		11.0	20.0	11.5	42.5	1.5	3.0	2.0	6.5	46	92	43	181	1	2	1	4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	C.1	C.1	C.1	C.1	C.2	N/A	N/A
UC-6	DRIVER	22.0	33.0	0.0	55.0	6.3	7.0	0.0	13.3	90	139	0	229	2	3	0	5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	C.1	C.1	C.1	C.1		N/A	N/A
		23.0	35.0	35.0	93.0	4.0	5.0	7.0	16.0	93	133	133	359	2	3	3	8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	C.1	C.1	C.1	C.1	C.2	N/A	N/A
UC-7	DRIVER	11.0	44.0	12.0	67.0	0.0	0.0	0.0	0.0	65	221	54	320	1	4	1	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	C.1	C.1	C.1	C.1		N/A	N/A
		22.5	31.0	22.0	75.5	0.0	0.0	0.0	0.0	106	151	99	356	2	3	2	7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.1	0.1	0.2	0.1	C.2	N/A	N/A
UC-8	DRIVER	19.5	38.0	0.0	57.5	0.0	0.0	0.0	0.0	115	222	0	337	2	4	0	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	C.1	C.1	C.1	C.1		N/A	N/A
		10.0	10.0	39.0	79.0	0.0	0.0	0.0	0.0	166	43	198	407	3	1	4	8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.1	0.1	0.1	0.2	C.2	N/A	N/A

NOTE: N/A = NOT APPLICABLE

was a loader operator who took drums of concentrate from one trailer and loaded them on another.

Monthly times spent in vehicles are shown in columns 3 to 6.

Monthly loading times are given in columns 7 to 10.

The numbers of drums handled are shown in columns 11 to 14.

The numbers of loads of drums handled are shown in columns 15 to 18.

The numbers of loads of slurry and raffinate hauled are given in columns 19 to 22 and 23 to 26, respectively.

The reported doses are summarized in columns 27 to 33.

7.5 Industrial Isotopes

The final type of radioactive materials handled by participants in the study is industrial isotopes. These materials, which are frequently used for testing such things as the integrity of welds and for measuring soil densities, are generally shipped in steel containers small enough to be handled manually. Labels are attached to these containers to identify their contents and to indicate the transport index.

The data for one participant who handled this type of package is summarized in Table 7.4.

In this table, the driver's designation is given in column 1.

The driver's monthly times in the vehicle are given in columns 3 to 6.

TABLE 7.4 - - - SUMMARY OF DATA RECEIVED FOR THE CARCINOGENIC HANDLING INDUSTRIAL ISOTOPES (II) - - -

DES'N	JOB	IN VEHICLE (hr)				LOADING & UNLOADING (hr)				TOTAL TRANSPORT INDICES				TRUCK SIZE	REPORTED DOSE (mSv)								
		O/J	B/F	B/H	TOTAL	O/J	B/F	B/H	TOTAL	O/J	B/F	B/H	TOTAL		O/J	B/F	B/H	O-B/J-H	OCT-MAR	CAB	AREA 1	AREA 2	AREA 3	AREA 4
II-1	DRIVER	68.5	67.5	18.5	167.5	1.0	1.4	0.6	3.0	20.1	32.4	3.0	55.5	32'	<.1	<.1	<.1	<.1		<.1	<.1	LOST	LOST	<.1
		47.5	86.0	57.5	191.0	2.1	2.2	1.6	5.9	32.1	36.9	33.6	102.6		<.1	<.1	<.1	<.1	<.2	<.1	LOST	<.1	LOST	LOST

Loading and unloading times are shown in columns 7 to 10. The total transport indices of the containers handled by the driver are presented in columns 11 to 14.

The truck size is shown in column 15.

Reported doses are provided in columns 16 to 25.

8.0 ASSESSMENT OF DATA

8.1 General

In this section, the data presented in Section 7 is reviewed and assessed according to the categories used previously. Part of this assessment pertains to compliance with the annual dose limit set for non-Atomic Radiation Workers (non-ARWs). As stated previously, this limit has been set in Canada at 5 mSv. Since the monitoring phase of the study was conducted over a period of six months, compliance with this limit would mean that total doses for the candidates during that period could be no greater than 2.5 mSv, if it is assumed that conditions of exposure to radiation remain the same throughout the entire year.

The total personal doses received by the candidates during the monitoring period were determined by adding together the results of their individual three-month badges, since this is the standard monitoring period for determining occupational exposures to ionizing radiation. As indicated later in this section, however, the results of the one-month badges were also reviewed when assessing the validity of the three-month results.

8.2 Medical Isotopes

As outlined in the previous section, the data collected for participants who handled medical isotopes is summarized in Table 7.1. In reviewing the figures presented in the column headed "OCT-MAR" in this table, it is apparent the some of the candidates who handle medical isotopes received reported doses of at least 2.5 mSv during the six-month monitoring period.

From the table it can also be seen that for the two participants (MI-1 and MI-6) who were issued cab badges and whose doses for each three-

month period were at least 0.2 mSv (the lowest level of assured positive occupational exposure since the stated accuracy of the dosimeters has been given as ± 0.1 mSv), the cab dose was less than half of the total personal dose. (For participant MI-4, however, the doses reported for the cab badges actually exceeded those reported for his personal badges but this can be explained by the fact that since only a small number of radioactive packages were handled, the participant probably spent more time away from the vehicle making deliveries than in the cab of the vehicle.) This data would indicate that doses received while handling the packages are generally greater than those associated with driving transport vehicles.

The data for participant MI-1 indicates a total reported dose of 6.7 mSv during the October to March monitoring period. It is interesting to note that while the vehicle times, loading and unloading times and numbers of packages handled increased in the second half of the study, the reported doses actually decreased from 4.4 to 2.3 mSv. This fact has been discussed with both the company contact and the person responsible for analyzing the dosimeters at BRMD. Since both individuals have indicated that the data is reliable, there does not seem to be an explanation for this decrease in reported dose, although the same trend can be seen for participants MI-9 and MI-10. The one-month badge results for participants M-1 and M-9 indicate an inexplicable reduction in dose during the months of February and March.

In reviewing the data presented in Table 7.1, it can be seen that only those participants who actually carry the packages of medical isotopes received doses of radiation of at least 2.5 mSv during the six-month monitoring period. It is also apparent that those with the higher doses handled a greater number of packages. To determine if a relationship exists between the number of packages handled and dose reported, linear regression analyses were carried out using the data collected for those participants who physically carry the packages and

whose doses for at least one three-month period were 0.2 mSv or greater (since the stated accuracy of the reported doses is ± 0.1 mSv).

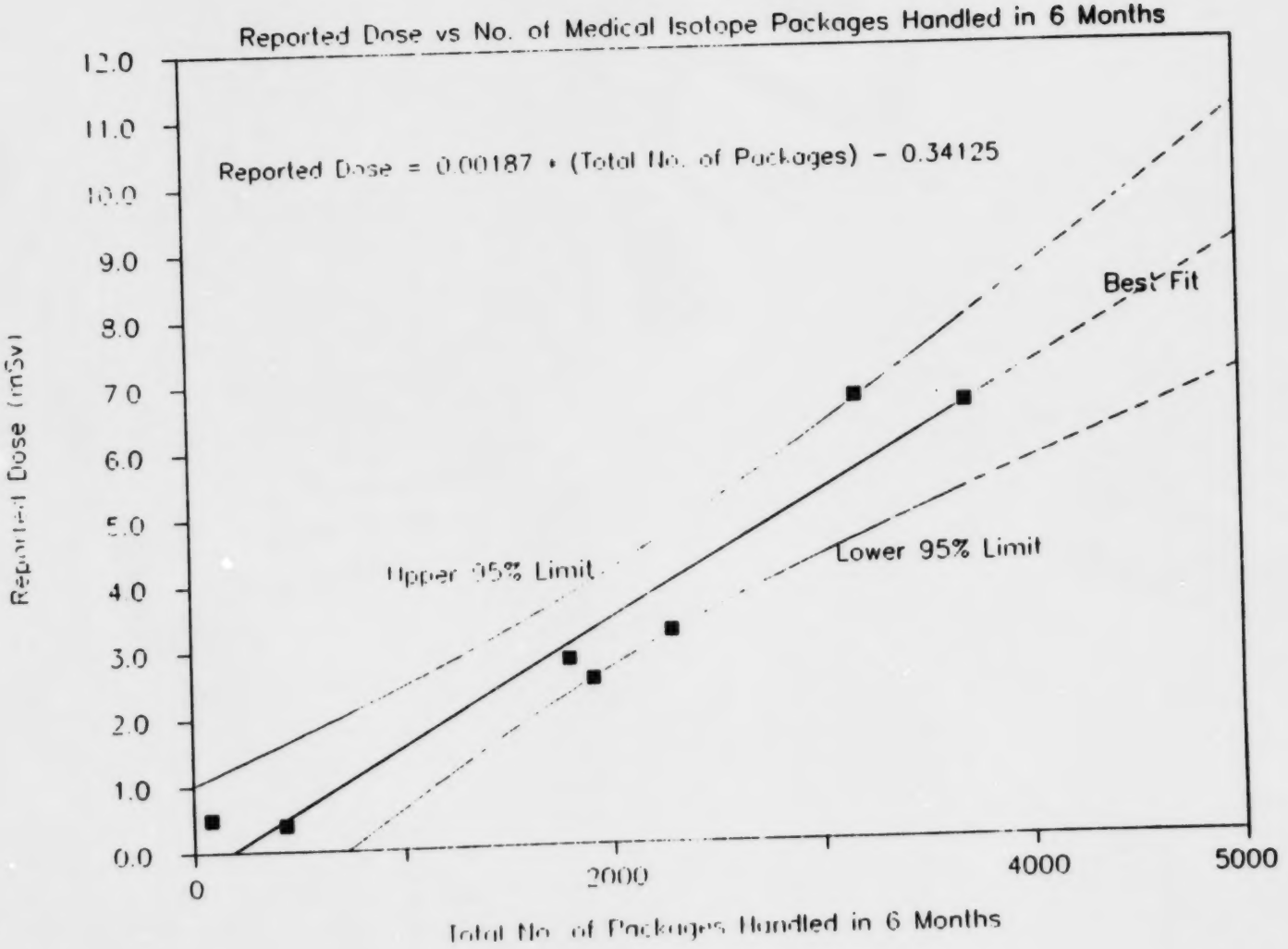
From Table 7.1, it can be seen that seven participants (MI-1, MI-2, MI-6, MI-9, MI-10, MI-12 and MI-14) satisfy the conditions cited above. (Although the reported doses for MI-13 are above background, the data collected for this individual was not used in the detailed analyses as he does not carry packages as part of his normal daily routine. It is interesting to note, however, that his reported doses for the January to March period dropped significantly from those for the October to December period. This decrease can be explained by the fact that the depot was expanded during the monitoring period and the radioactive materials are now handled at the back of the building. Since the participant spends less time in the general vicinity of these materials, a decrease in exposure would be anticipated.)

The data collected for these seven individuals was extensively reviewed and used to develop a number of correlations between dose reported and materials handled. Pertinent statistical data for these correlations (and others to be discussed later) is summarized in Table 8.1. Additional supporting data is provided in Appendix D.

In Table 8.1, the figure numbers for the various correlations are shown in the first column (Figures D-1, D-2, D-3A and D-3B are found in Appendix D). Descriptions of the correlations are given in the second column. Slopes and intercepts for the "best fit" lines developed for these correlations are presented in the third and fourth columns. The coefficient of determination (r^2) and the correlation coefficient (r) for each correlation are given in columns five and six, respectively.

To assess the validity of these correlations, they were tested on the basis of determining if the hypothesis of a zero correlation (i.e. if the slope of the correlation was equal to zero thus indicating that no

Figure 8-1


Reported Dose vs No. of Medical Isotope Packages Handled in 6 Months
Reported Dose = 0.00187 * (Total No. of Packages) - 0.34125
Best Fit
Upper 95% Limit
Lower 95% Limit
Reported Dose (mSv)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
2000
4000
5000
Total No. of Packages Handled in 6 Months

correlation exists between reported dose and the various parameters) was true. This "null hypothesis" was tested at both the 95% and 99% confidence levels using the critical r values shown in columns seven and nine. If the correlation coefficient in column six exceeds the critical r value, the null hypothesis (i.e. the hypothesis that no correlation exists) is not accepted. While it is not possible to statistically prove that a correlation does exist, it is possible to state with a given level of confidence, that the assumption of no correlation is untrue. Therefore in columns eight and ten, "accepted" indicates that at the stated level of confidence, the hypothesis of no correlation is accepted and "not accepted" indicates that the hypothesis is not accepted.

In reviewing the data presented in Table 8.1, it should be noted that the coefficient of determination (r^2) is a measure of the strength of the correlation (i.e. the influence of the variation in one parameter on the changes in the second). A perfect correlation has a coefficient of determination of 1.0. For the correlations pertaining to handlers of medical isotopes (Figures 8-1, D-1, D-2, D-3A and D-3B), it can be seen that the one shown in Figure 8-1 has the highest r^2 value (0.92813).

In Figure 8-1, the semi-annual doses (obtained by adding the quarterly doses together) reported for the seven participants are plotted against the total number of packages of medical isotopes that were handled during the monitoring period. The "best fit" line was determined by linear regression analyses. The 95% confidence limits were established by the procedure outlined in Appendix D.

Supporting data for this correlation as well as the others discussed in this section, is provided in Appendix D.

TABLE 8.1

SUMMARY OF PERTINENT STATISTICAL DATA FOR CORRELATIONS

FIGURE	CORRELATION	SLOPE	INTERCEPT	COEFFICIENT OF DETERMINATION (r^2)	CORRELATION COEFFICIENT (r)	95% CRITICAL r VALUE	NULL HYPOTHESIS CONCLUSION (1)	99% CRITICAL r VALUE	NULL HYPOTHESIS CONCLUSION (1)
8-1	DOSE vs NO. OF MED. ISOTOPE PACKAGES HANDLED IN 3 MONTHS	0.00187	-0.34125	0.92813	0.963	0.755	NOT ACCEPTED	0.875	NOT ACCEPTED
8-2	DOSE vs NO. OF HOURS HAULING UF_6 CYLINDERS	0.00126	0.05658	0.96992	0.985	0.997	ACCEPTED (2)	1.000	ACCEPTED (2)
8-3	DOSE vs NO. OF WASTE CONTAINERS HAULED	0.00125	0.01875	1.00000	N/A (3)	N/A (3)		N/A (3)	
D-1	DOSE vs NO. OF MED. ISOTOPE PACKAGES HANDLED IN 3 MONTHS	0.00184	-0.14028	0.66721	0.817	0.532	NOT ACCEPTED	0.661	NOT ACCEPTED
D-2	DOSE vs NO. OF CAT. II & III PACKAGES HANDLED IN 6 MONTHS	0.00204	-0.32272	0.92726	0.963	0.755	NOT ACCEPTED	0.875	NOT ACCEPTED
D-3A	DOSE vs WEIGHTED (TYP.) NO. OF PACKAGES HANDLED IN 6 MONTHS	0.00302	-0.36920	0.77720	0.882	0.755	NOT ACCEPTED	0.875	NOT ACCEPTED
D-3B	DOSE vs WEIGHTED (AVG.) NO. OF PACKAGES HANDLED IN 6 MONTHS	0.00075	-0.32600	0.74634	0.864	0.755	NOT ACCEPTED	0.875	ACCEPTED

NOTES: (1) "Accepted" indicates that at the stated level of confidence, the hypothesis of no correlation (null hypothesis) is accepted.

"Not accepted" indicates that the null hypothesis of no correlation is not accepted. This is not statistically equal to stating that there is a correlation.

The null hypothesis is not accepted if the correlation coefficient is greater than the critical r value.

(2) The null hypothesis has not been proven primarily due to the small sample size.

(3) Not applicable since only two data points were available to develop the correlation.

8.3 Exclusive Use Containers

The data collected for the handlers of exclusive use containers is summarized in Table 7.2. In reviewing this data, it would appear that participant EU-1, a driver hauling UF_6 cylinders, is likely to receive a whole body dose exceeding the annual limit of 5 mSv set for members of the general public. Close examination of his dosimetry results shows that he apparently received a much larger dose in the first half of the study than in the second half. It is also evident that a major dose was received during the month of October. In view of the fact that the times and quantities reported for the month were not significantly different from those reported for the other months, the individual was contacted personally to determine if there was an explanation for these apparently anomalous readings. After reviewing the log book entries for the month, this individual indicated that there was nothing abnormal about the activities carried out. It was mentioned that he had spent one night in the sleeper compartment of his truck but gamma readings taken from within this compartment suggest that this might result in an dose of only about 0.3 mSv. This individual's doses are monitored on a regular basis by an American company that issues quarterly dosimeters similar to those employed in the study. With the permission of the participant, a copy of his recent dosimetry data from the American company was obtained and reviewed. This data confirmed that October to December doses were substantially higher than those for the January to March period. Since this individual handles the same materials and travels the same routes as a number of other drivers from the company, historical data for these other drivers was also examined. When it became apparent that other drivers were not receiving doses as large as those reported for the participant, and that he has shown elevated levels in the past, he was questioned about his medical history (i.e. if he had been subjected to radiation diagnostic or therapeutic procedures). He responded that nothing abnormal has taken place. To determine if he was receiving additional non-occupational exposures, his residence and vehicles were

Figure 8-3

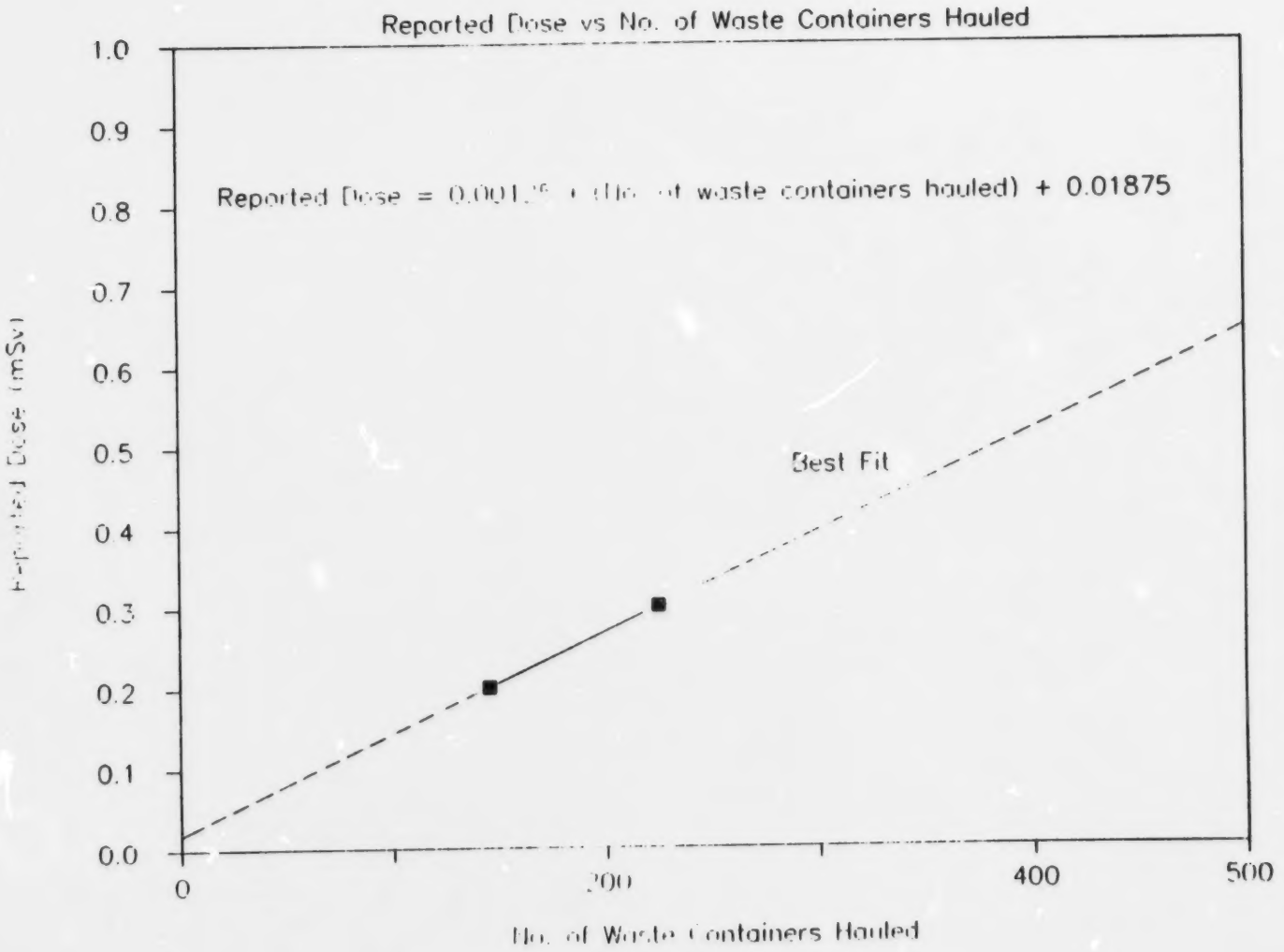
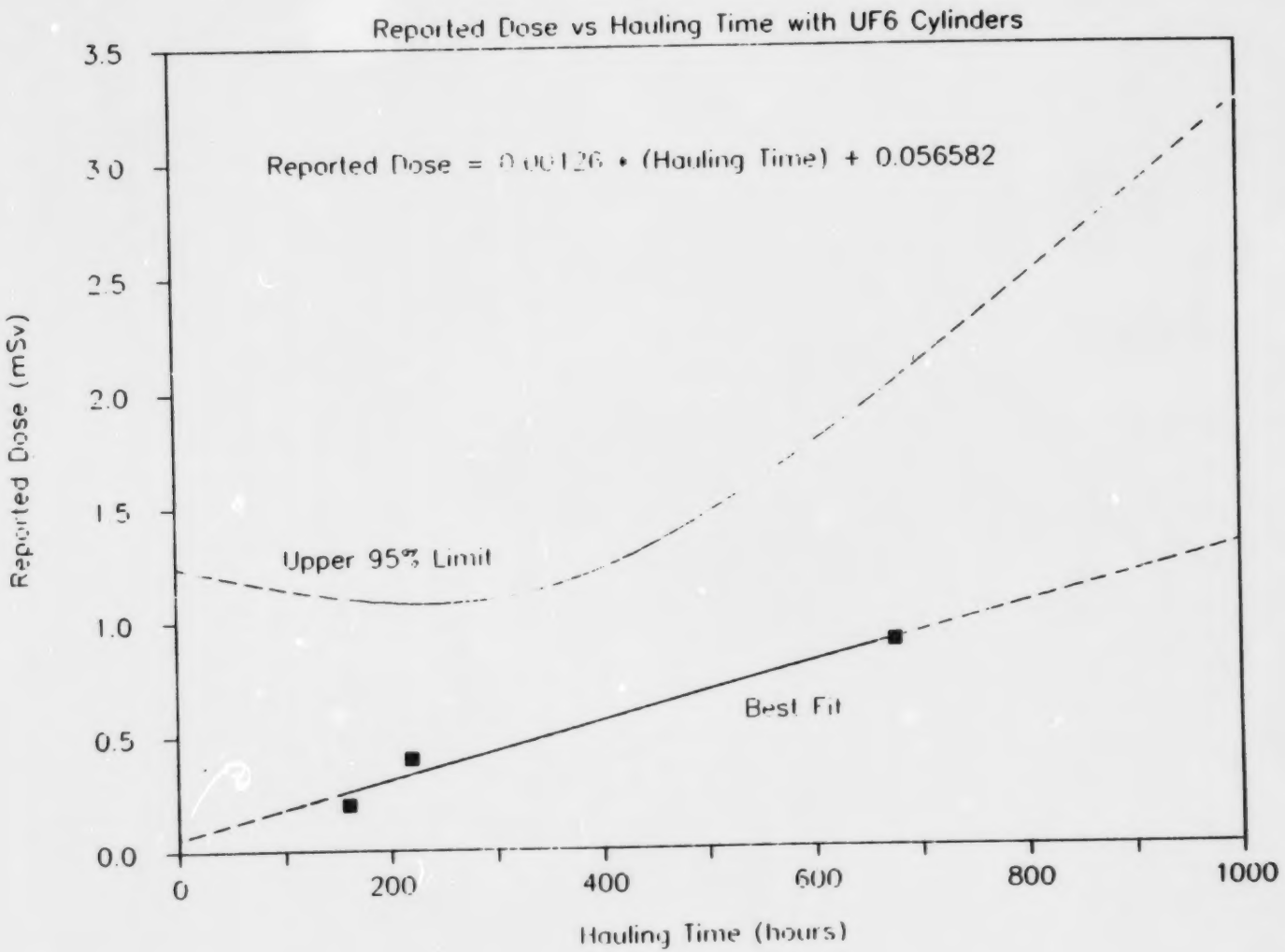

Reported Dose vs No. of Waste Containers Hauled
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Reported Dose = 0.001
waste containers hauled) + 0.01875
Best Fit
0
200
400
500
No. of Waste Containers Hauled

Figure 8-2


Reported Dose vs Hauling Time with UF6 Cylinders
Reported Dose = 0.00126 • (Hauling Time) + 0.056582
Upper 95% Limit
Best Fit
Reported Dose (mSv)
Hauling Time (hours)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
200
400
600
800
1000

checked for sources of radioactivity. To date, no explanation for these readings has been found. The doses reported for the other UF_6 driver, although above background, were much lower.

A correlation between driving time and dose received was developed for haulers of UF_6 cylinders. In view of the fact that no reason for the elevated October to December doses for participant EU-1 has been determined, only his January to March data and the 6-month data for participant EU-2 were used to produce the correlation shown on Figure 8-2. The results of this correlation are summarized in Table 8.1 and supporting data is presented in Appendix D of this report. It should be noted, however, that the reliability of this correlation is suspect due to the limited amount of data available.

A review of the remaining data in Table 7.2, reveals that there were only two other participants involved in the handling of exclusive use containers for whom detectable doses were reported. The first is participant EU-7, a driver who hauls UO_3, who apparently received a dose of 0.4 mSv during the second half of the monitoring period. Close examination of his data along with that of participants EU-5 and EU-6, the other drivers who haul this material, suggests that this is an anomalous reading since the other drivers handled similar quantities of materials and spent similar times in their vehicles. The monthly data for this individual also supports this conclusion.

The second individual with detectable doses is participant EU-8, a driver who hauls waste materials in exclusive use containers. Since there was only one driver who hauls these types of containers included in the study, only limited data is available. Using this data, a correlation between dose received and the number of containers hauled was developed. This correlation is shown in Figure 8-3 and summarized in Table 8.1. It should be noted that since this correlation was developed from the data collected for only one individual and is based on only two data points, neither the correlation coefficient nor

confidence limits could be calculated. This limited amount of data also reduces the reliability of this correlation. It is evident, however, that unless conditions change dramatically, the participant is not likely to receive a whole body dose close to maximum annual limit for the general public.

Supporting data for this correlation is given in Appendix D of this report.

8.4 Uranium Concentrate

The data for handlers of uranium concentrate presented in Table 7.3 indicates that none of the participants received six-month doses above 2.5 mSv and that only four of them received doses that were distinguishable from background on their three-month badges. The data for participant UC-1 shows an a reported dose of 0.3 mSv for the October to December period but one that is indistinguishable from background for January to March. In reviewing the reported times and quantities handled for the two halves of the monitoring period, however, there does not seem to be a logical explanation for the difference in the doses reported. The one-month badge results also indicate that the 0.3 mSv value might be high. Even if this is a valid number, however, the annual dose would be well within the 5-mSv limit for the general public.

Three-month doses for participant UC-2 were reported as 0.3 and 0.5 mSv. Although the loading times and number of drums handled suggest that the trend should be reversed, the semi-annual total for the individual is well below 2.5 mSv. It is interesting to note that the doses reported for the area badges indicate that a large portion (60-80%) of the personal dose is received from working in the area where the drums are stored.

The data in Table 7.3 for participants UC-7 and UC-8 indicates that they received doses that were indistinguishable from background in the first half of the monitoring period, but the doses for the January to March period were reported as 0.1 and 0.2 mSv, respectively. Although this trend is also evident from the monthly data for these participants, it is interesting to note that for participant UC-6 only background doses were reported even though he handled a similar number of drums and spent more time in his vehicle.

Due to the low doses reported and the inexplicable trends previously discussed, no correlation between dose received and materials handled was developed for those who handle uranium concentrate. It is evident, however, that none of the participants involved in the handling of these materials is likely to receive an annual doses close to the 5-mSv limit established for members of the general public.

8.5 Industrial Isotopes

As indicated in Table 7.4, one of the participants in the study handles industrial isotopes during the course of his normal working day. This individual kept a record of the transport index indicated on each of the containers handled during the monitoring period. From the data in Table 7.4, it can be seen that the doses reported were indistinguishable from background even when the total of the transport indices of the containers handled during a three-month period exceeded 100. Since there were no positive doses reported for this participant, it was not possible to develop a correlation between dose received and industrial isotopes handled.

Although several of the area badges used in the depot were lost, those that were retrieved showed exposure levels that were indistinguishable from background. It is therefore apparent that no significant doses are being received by those who work in the depot.

9.0 CONCLUSIONS

As outlined earlier in this report, this study was carried out to determine actual doses of radiation that were received by a select group of individuals who, during their normal work period, are involved in the handling of radioactive materials. These individuals also documented their daily activities associated with the handling of these materials so that correlations could be developed between the quantity of materials handled or handling time and dose received. The data obtained in addition to other information can be used by the Atomic Energy Control Board to determine if there are transport workers who, while handling radioactive materials on a regular basis, receive sufficiently large doses of ionizing radiation that they should be reclassified as Atomic Radiation Workers (ARWs).

From previous discussions, it can be concluded that most of the participants in the study are likely to receive annual doses that are well below the 5-mSv limit.

There are other individuals, however, whose annual doses based on the six-month study, will probably exceed the 5-mSv limit. These individuals are primarily employees of courier companies who physically carry medical isotopes as part of their normal work load. As expected, the doses received by these individuals are directly proportional to the number of packages of isotopes handled. These companies generally pick up the isotopes at the facilities where they are produced, take them to a depot where they are sorted according to destination, ship them to the depot closest to the destination and then deliver them to the medical facility at which they are to be used. Between initial pickup and final delivery, it is therefore possible that several employees will come into direct contact with these packages.

From the correlation shown on Figure 8-1, it is possible to estimate

doses for individuals handling medical isotopes by determining the number of packages that they carry during a specific period of time.

In addition to the handlers of medical isotopes, haulers of UF_6 cylinders and certain containers of radioactive wastes were also found to receive doses that exceed natural background levels. From the correlations presented on Figures 8-2 and 8-3, it is possible to estimate doses for haulers of these UF_6 cylinders and waste containers, respectively. Based on these correlations, it is expected that under normal circumstances, haulers of these materials are not likely to receive doses above the 5-mSv annual limit set for members of the general public.

In conclusion, it can be said that certain handlers of particular types of radioactive materials are likely to receive occupational doses of ionizing radiation that exceed the annual limit of 5 mSv set for members of the general public. From the results of this study carried out on a select group of road transport workers, however, annual doses are likely to be less than 14 mSv. Such doses are well below the annual limit of 50 mSv set for Atomic Radiation Workers.

10.0 RECOMMENDATIONS FOR FUTURE WORK

10.1 General

From previous discussions, it is evident that most of the participants in the study receive very low doses of radiation from the handling of radioactive materials. There are some handlers of medical isotopes, however, who are not currently classified as ARWs but who are likely to receive annual whole body doses exceeding the maximum limit set for members of the general public. It is also evident that there were some unanswered questions with respect to the doses reported for one UF_6 driver. Based on these facts, it is recommended that further work be carried out to support these findings and to provide solutions to the unanswered questions.

10.2 Medical Isotopes

The data collected for participants handling medical isotopes was collected from only two depots and for a period of only six months. In view of the reverse trends previously discussed, and to provide additional data, it is recommended that further monitoring be carried out at more depots and that it extend for a period of one year.

Since there are a number of depots throughout the country where these materials are handled, it would be possible for example, to estimate the number of these packages entering a specific facility and then decide if the monitoring of individuals is warranted. Initially, a conservative approach could be adopted and if, for example, it is known that a minimum of 1000 packages pass through particular depots in a year (resulting in an anticipated annual dose of less than 2 mSv for handlers of these materials), those individuals directly involved in handling these packages could be monitored for a specific length of time. If very low doses were reported, the minimum number of packages handled at the depots where monitoring is carried out, could be raised.

Another approach might be to monitor, for a specific time period, the sorters at every depot where medical isotopes are handled on a regular basis. At the end of that period, those who are receiving negligible doses would no longer require monitoring. At those depots where significant doses are being received, a close look at the handling methods of the other employees could be carried out to determine if there are other individuals who should also be monitored.

10.3 UF_6 Cylinders

In view of the unanswered questions pertaining to one of the participants who handled UF_6 cylinders, it is recommended that this individual along with others from the same company be monitored for an extended period of time to try to determine an explanation for the significant doses reported in the past.

Since this individual is currently being monitored by others on an ongoing basis, it would probably be convenient to continue duplicate monitoring until the source of his exposures has been identified.

It is recommended that the individual be issued a number of additional badges. One would be replaced after each trip (approximately 3-5 days). Another would be replaced after it had been in service for a period of one-month and a third would be replaced quarterly. Since there are other drivers travelling similar routes, it is recommended that at least one other driver also be issued these additional badges. This additional monitoring could be continued until the source or sources of the inexplicable exposures are identified. The possibility of additional monitoring for this participant has been discussed with him and he has expressed a sincere desire to co-operate as he is most anxious to receive an explanation for his reported doses.

10.4 Additional Information

As indicated previously, this study was undertaken to determine the doses of ionizing radiation received by a select group of Canadian transport workers who handle a variety of radioactive materials and to relate these doses to the type and quantity of materials handled. The selection of participants in the study was carried out on a systematic basis to include the major carriers of a variety of types of materials. Although the study was not intended to address all types of radioactive materials, it was learned that workers handling some types of materials are, under certain circumstances, likely to receive annual doses that exceed the limit set for members of the general public.

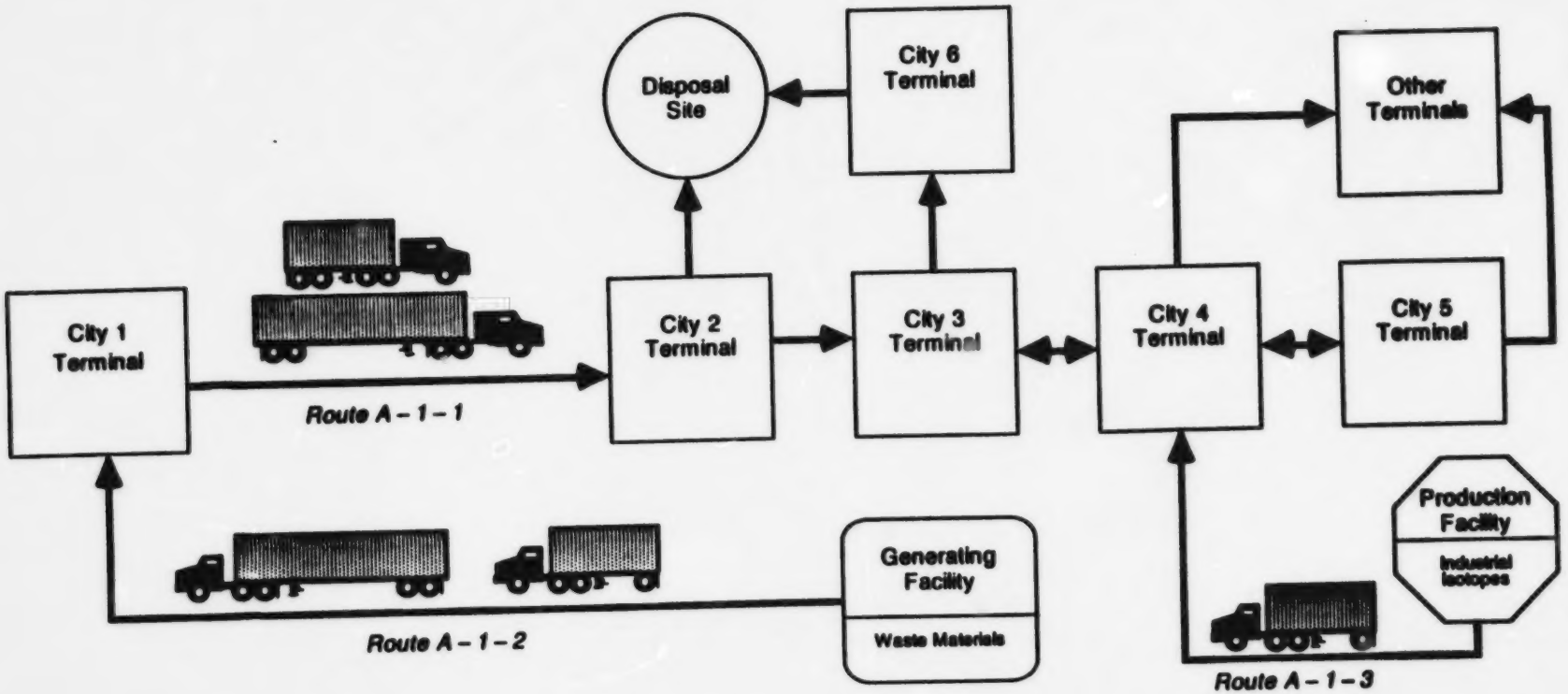
It is therefore recommended that a comprehensive overview of the shipment of radioactive materials by the Canadian transportation industry be carried out to determine if there are workers other than those represented by the study participants who, because of the materials handled or methods employed, may be exposed to levels of ionizing radiation greater than those set for the general public. While all modes of transportation could be involved in a study of this nature, it is recommended that at least road transportation be included. It is suggested that the study address, but not be limited to, the following issues:

- the total number of firms handling radioactive materials
- the methods and vehicles employed by these firms
- the types and quantities of materials handled
- the number of employees handling these materials
- suggestions for monitoring
- worker familiarity with materials handled
- preparations for emergencies.

The data collected during the initial study would provide an excellent basis on which to carry out a more comprehensive investigation of the shipment of radioactive materials throughout our country.

APPENDIX A

ILLUSTRATIVE SCHEMATICS FOR PARTICIPATING COMPANIES

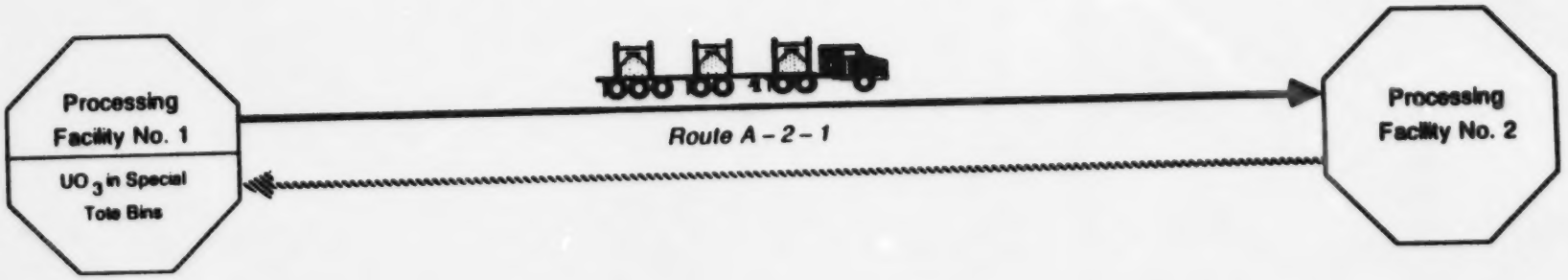


Measured Gamma Activities (μSv/hr)

Route	Cab	Contact
A – 1 – 1	0.20	90
A – 1 – 3	0.30	70

Figure A – 1

43915

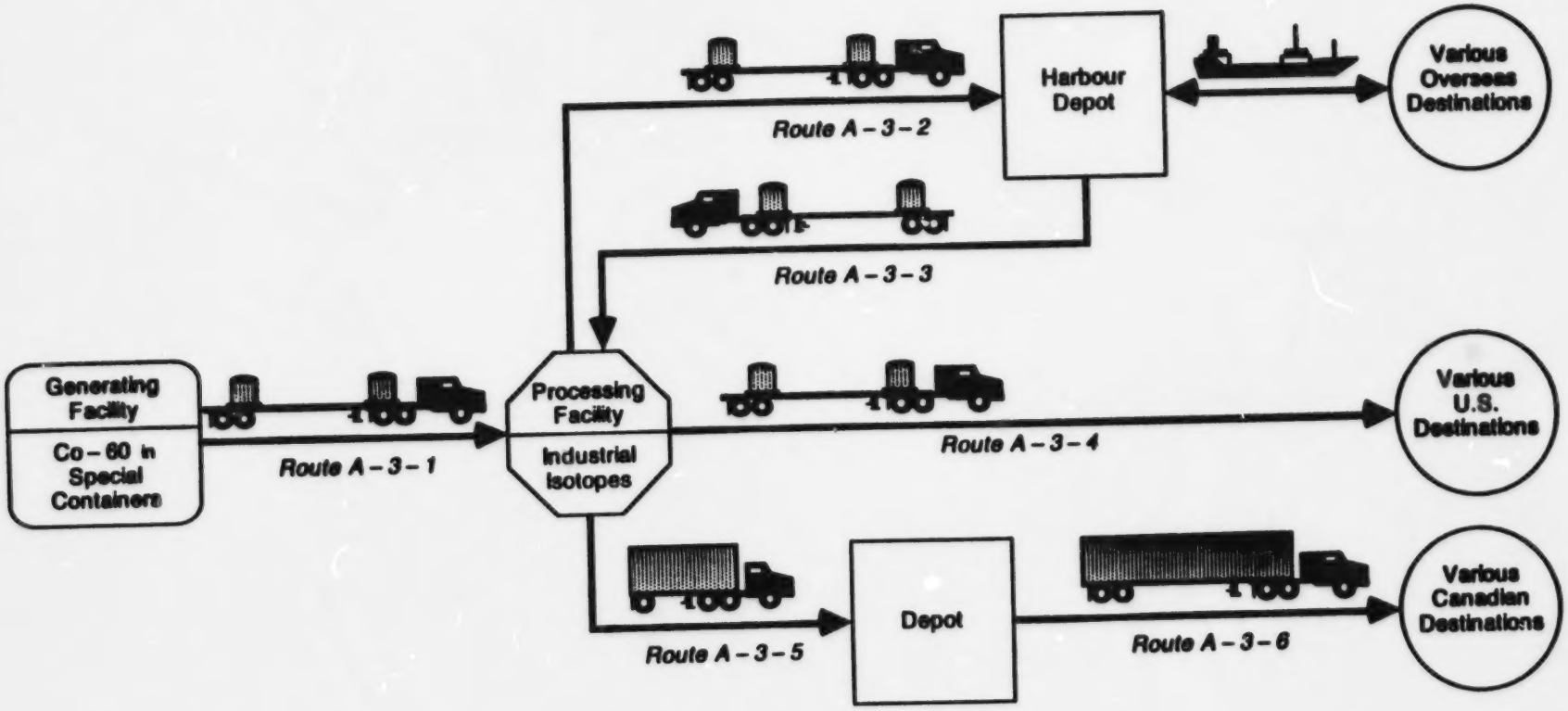


Measured Gamma Activities (μSv/hr)

Route	Cab	Sleeper	Contact
A – 2 – 1 (outbound)	0.25	0.45 – 0.50	12

Figure A – 2

43915

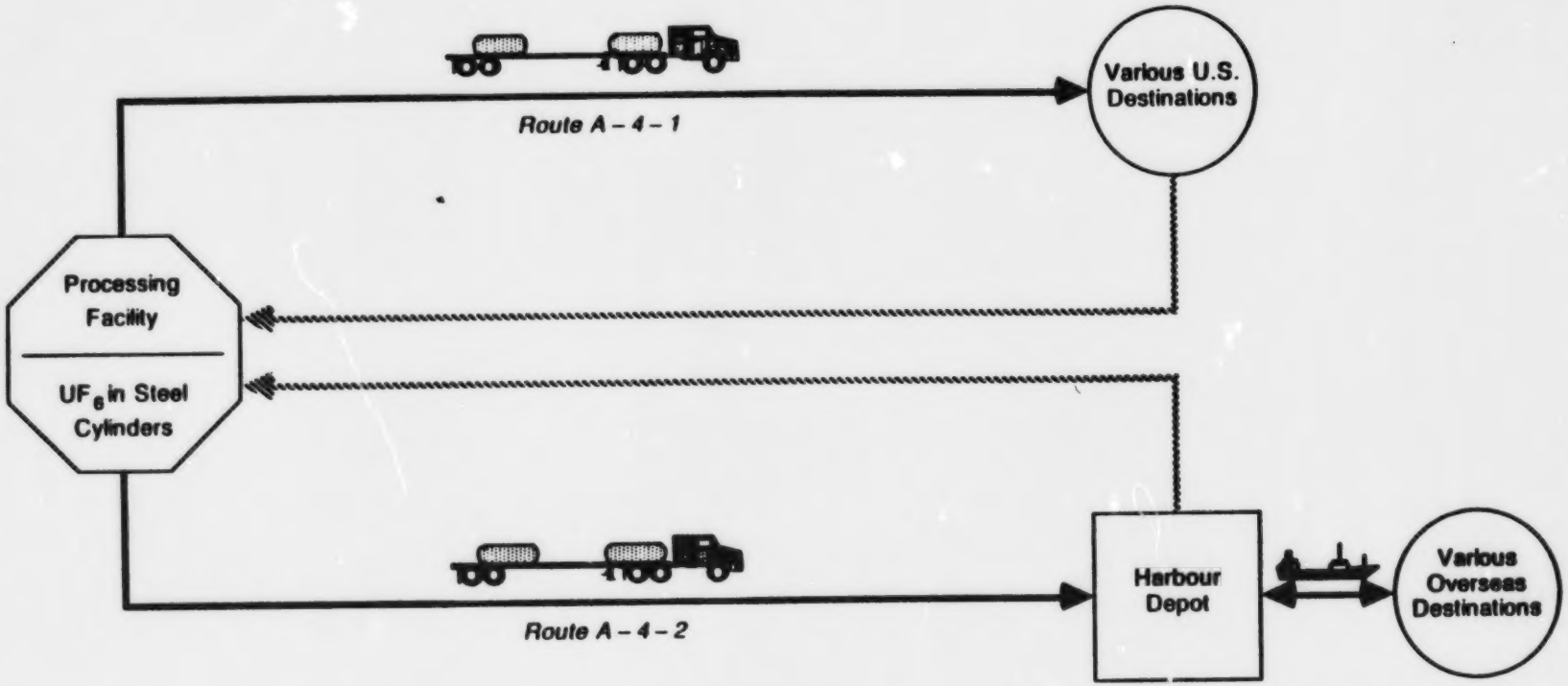

Generating Facility
Co – 60 in Special Containers
Route A – 3 – 1
Processing Facility
Industrial Isotopes
Route A – 3 – 2
Harbour Depot
Various Oversees Destinations
Route A – 3 – 3
Route A – 3 – 4
Various U.S. Destinations
Route A – 3 – 5
Depot
Route A – 3 – 6
Various Canadian Destinations

Measured Gamma Activities (μSv/hr)

Route	Cab	Sleeper	Contact
A – 3 – 1	0.25	0.40	50
A – 3 – 2	3.0 – 3.5	4.0 – 5.0	300
A – 3 – 3	3.0 – 3.5	4.0 – 4.5	300
A – 3 – 4	0.3 – 0.5	Not Applicable	150
A – 3 – 5	0.05	0.05	150

Figure A – 3

43915

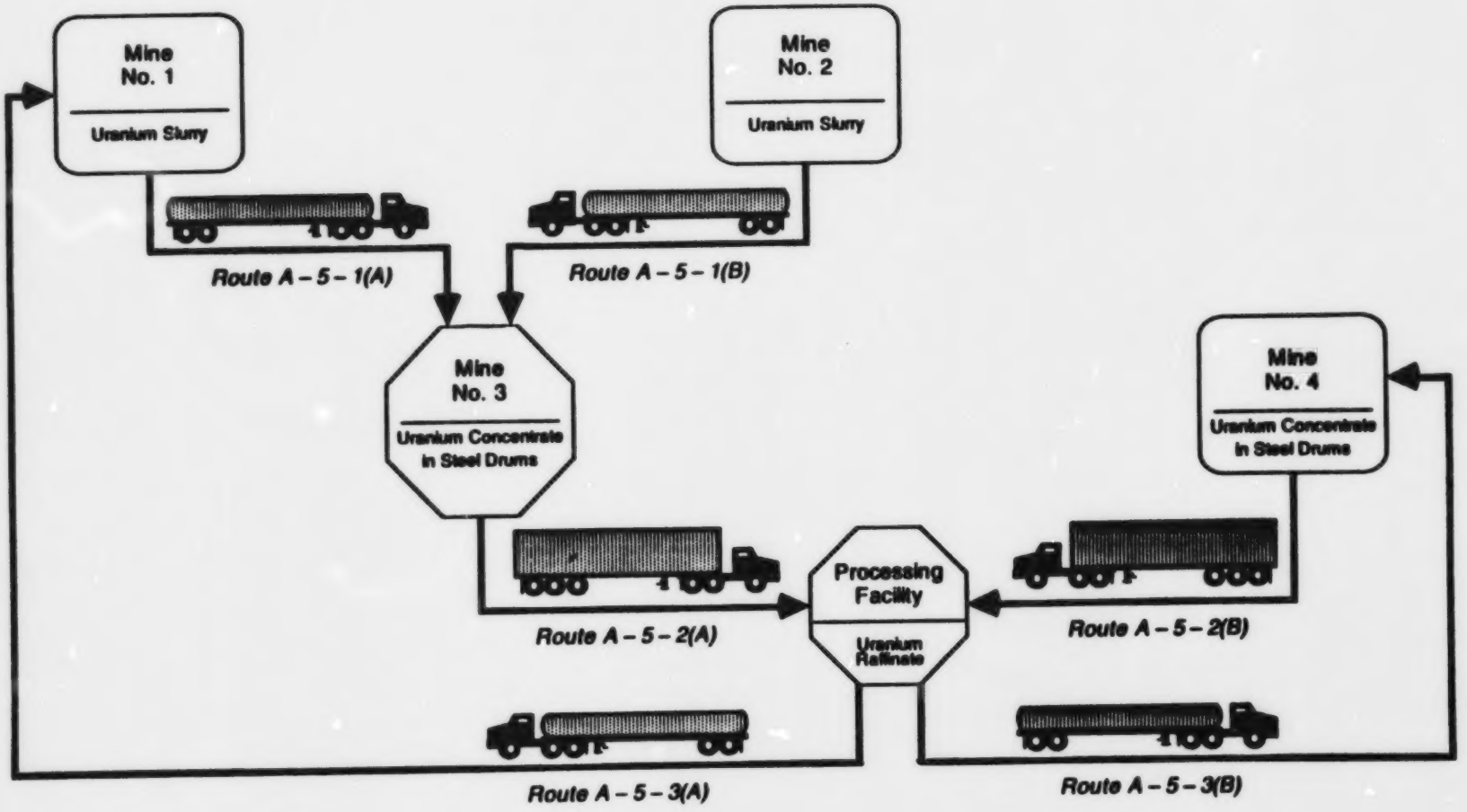


Measured Gamma Activities (μSv/hr)

Route	Cab	Sleeper	Contact
A – 4 – 1 (outbound with full cylinders)	0.15 – 0.30	0.40 – 0.60	15
A – 4 – 1 (inbound with empty cylinders)	1.20 – 2.00	2.50 – 4.00	+ 50

43915

Figure A – 4

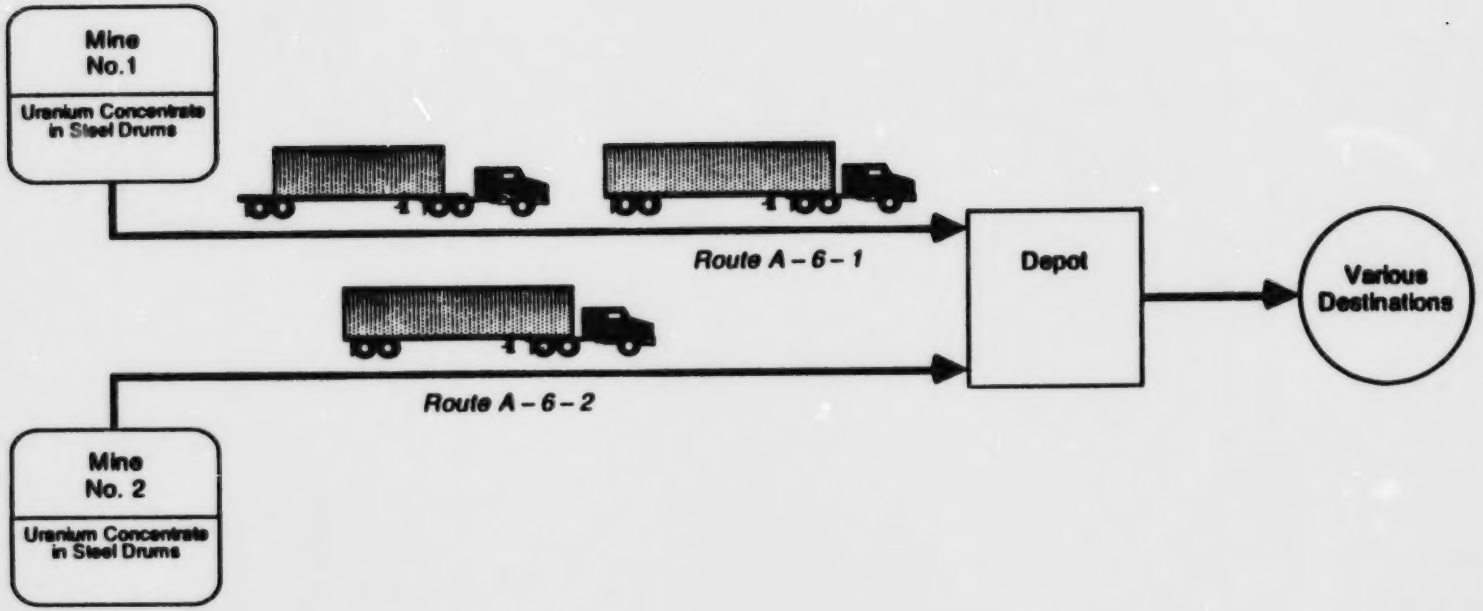


Measured Gamma Activities (μSv/hr)

Route	Cab	Contact
A – 5 – 1	0.75 – 1.0	16
A – 5 – 2	2.8 – 3.0	30
A – 5 – 3	1.5	+ 50

43915

Figure A – 5



Measured Gamma Activities (μSv/hr)

Route	Cab	Sleeper	Contact
A – 6 – 1 Container (35 drums)	0.20	0.40	1.0 – 50
A – 6 – 1 Van (45 drums)	0.20	0.40	1.0 – 50

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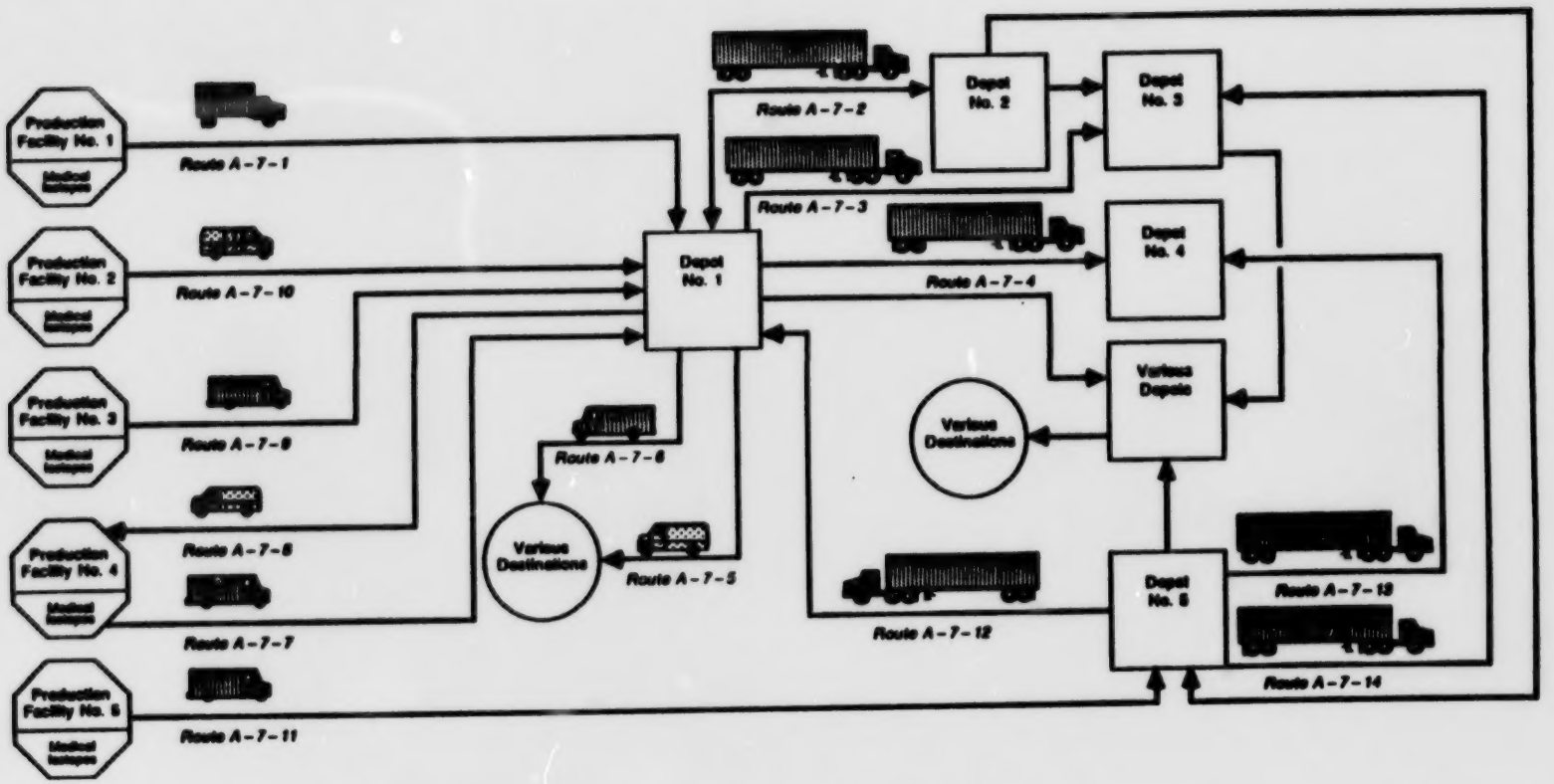
Figure A – 6



Measured Gamma Activities (μ Sv/hr)

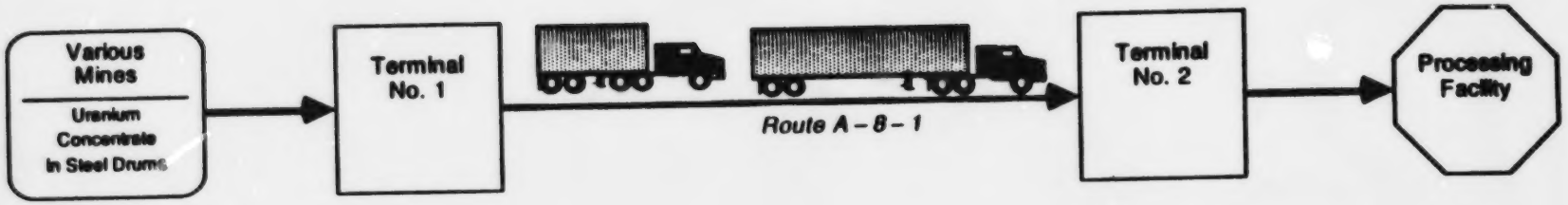
Route	Cab	Contact
A-7-1	1.0-1.51	200
A-7-2 (Sunday)	3.5-5.0	+50
A-7-3(a) (outbound)	-	-
A-7-3(b) (inbound Sunday)	0.15-0.20	+50
A-7-4	-	-
A-7-5 (Saturday)	+50	+50
A-7-6	N/A	N/A
A-7-7	N/A	N/A
A-7-8 (Sunday)	30-32	+50
A-7-9 (Sunday)	50	+50
A-7-10 (by others)	-	-

Measured Gamma Activities (μ Sv/hr)

Route	Cab	Contact
A-7-11	N/A	+50
A-7-12	0.15-0.20	+50
A-7-13	0.15-0.20	+50
A-7-14	0.15-0.20	+50

45916

Figure A-7

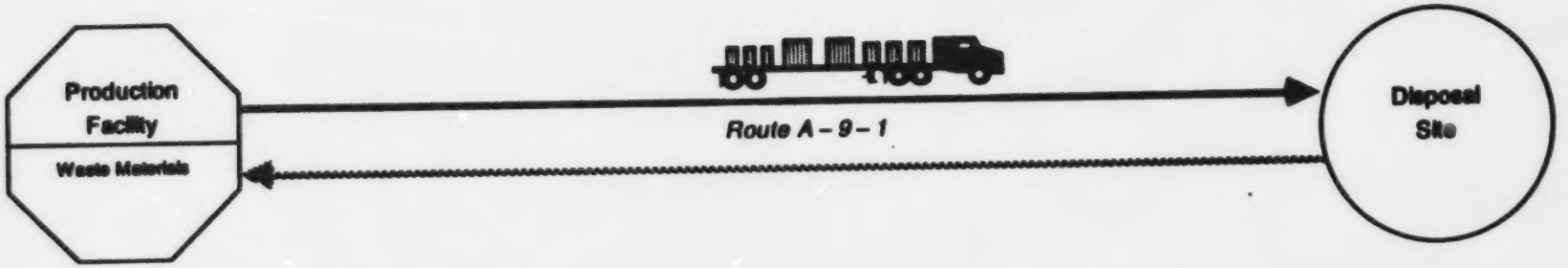


Measured Gamma Activities (μSv/hr)

Route	Cab	Sleeper	Contact
A – 8 – 1 (45 foot trailer)	0.40 – 0.45	1.5 – 1.8	25 – 45
A – 8 – 1 (26 foot trailer)	1.2 – 1.4	2.5 – 3.0	25 – 45

Figure A – 8

43915



Measured Gamma Activities (μSv/hr)

Route	Cab	Sleeper	Contact
A – 9 – 1 (outbound)	1.0	1.5 – 1.8	+ 50.0
A – 9 – 1 (inbound)	0.1	0.1	0.2

43915

Figure A – 9

APPENDIX B

INFORMATION ON THERMOLUMINESCENT DOSIMETRY

THERMOLUMINESCENCE

THEORY & APPLICATIONS

By DONALD E. LANCASTER

Certain materials, when heated, release light proportional to previous radiation dosage. This provides a powerful, versatile tool for solid-state research, nuclear safety, medical dosimetry, geological age determination, and for archeological dating.

TAKE a chunk of limestone and crush it. Now heat it at a constant rate to kitchen-stove temperatures under laboratory conditions. It will probably emit light, but only while the temperature is *increasing*. Cool it back down again and repeat the process. Nothing happens. This strange behavior is an example of *thermoluminescence*, a new and valuable tool of use to the solid-state researcher, the nuclear scientist, the medical doctor, the geologist, and the archeologist.

Thermoluminescence is the release of light in a crystalline material as it is heated at a constant rate. The light is proportional to the previous nuclear radiation dosage the material has received. Once the light is produced, the previous radiation history of the material is "erased" as the thermal cycling performs a destructive readout of the sample's past history.

Had we measured the output light produced by the limestone sample and made a few other measurements and assumptions, we could find out either *how old* the limestone is or else *how long* it has been since it had last been heated. Conversely, we could heat-cycle our piece of limestone to erase all the old radiation history. Any measurement made in the future on this sample would tell us how much new radiation the limestone had been exposed to since we last heat-cycled it.

Thermoluminescence is then a two-way street; it can either tell us how long it has been since a substance was last heated, if we make some assumptions about dosage rate; or it can tell us how much radiation has been picked up in a given time. The "how long?" is of value to geologists and archeologists; the "how much?" is important to doctors using radioactive treatment and to nuclear scientists and other personnel exposed to possibly dangerous radiation levels.

Before looking further at this new field and its exciting applications, we must note that thermoluminescence is a very specific effect. It should not be confused with *incandescence* or *luminescence*, the ordinary light you get when you heat something up red hot or hotter. The temperatures involved in thermoluminescence are far lower. While the maximum temperature involved is around 600°F, most of the light is obtained at much lower temperatures. In fact, ice can be made to thermoluminesce.

The Basic Mechanism

Crystals can suffer radiation damage just like people can, and the damage is a cumulative effect that can be picked up in a single big blast of radiation, or over a very long time at very low radiation levels. Consider a crystalline substance that is also an insulator or a semiconductor. Table salt will do. Assume that it is initially a perfect crystal, without any impurities or mechanical problems. If we looked down into the crystal, we'd see a *crystal lattice*, a nice orderly arrangement of sodium and chlorine ions, one after the other, alternating in all three directions. Strong forces, called *valence bonds*, will try to hold all the ions in perfect alignment. Should we heat the crystal, thermal agitation will excite the individual ions. The higher the temperature, the greater the ion energy level, and the more likely the valence bonds will be broken. If we provide too much heat, the bonds all break and the crystal melts.

Table 1. A listing of various thermoluminescent materials.

MATERIALS	MINERALS	CHEMICALS
Ancient pottery	Alumina	Barium titinate
Bone	Anhydrite	Barium fluoride
Boiling stones (prehistoric cookers)	Anthracene	Calcium carbonate
Ceramics	Borate glass	Calcium oxide
Firepits	Calcite	Calcium fluoride*
Fossil shells	Clays	Calcium sulfate*
Glass	Diamond	Calcium sulfide
Ice	Dolomite	Cesium bromide (AH)
Meteors	Fluorite	Cesium iodide (AH)
Moon	Limestone	Lithium borate*
Polyethylene	Magnesite	Lithium bromide (AH)
Pottery kilns	Obsidian	Lithium chloride (AH)
Roof tiles	Quartz	Lithium fluoride (AH)*
Salt	Sandstone	Lithium phosphate
Sand	Sapphire	Magnesium oxide
Volcanoes	Silica	Magnesium sulfide
	Talc	Potassium bromide (AH)
		Potassium chloride (AH)
		Potassium fluoride (AH)
		Potassium iodide (AH)
		Potassium sulfate*
		Rhubidium bromide (AH)
		Rhubidium chloride (AH)
		Rhubidium iodide (AH)
		Silicon dioxide
		Sodium bromide (AH)
		Sodium chloride (AH)
		Sodium fluoride (AH)
		Sodium iodide (AH)
		Thorium dioxide
		Zinc oxide
		Zinc sulfide

(AH) = alkali halide; * = popular dosimetry material.

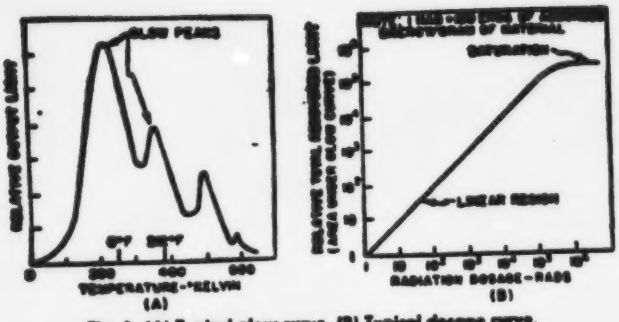


Fig. 1. (A) Typical glow curve. (B) Typical dosage curve.

Things are fine with our crystal until some high-energy particle comes along—the familiar *alpha*, *beta*, or *gamma* particles we'd get in any nuclear reaction, or perhaps a particle from an ultraviolet laser. One of these particles can "blast" one of the ions and literally knock an electron into orbit. In the process, the electron gets its own energy level raised so high that it cannot be recaptured by its own ion, and thus is free to wander throughout the crystal lattice. If more and more particles strike the crystal, more electrons get knocked loose and are free to roam around the crystal; they all have too much energy to get recaptured, and an electron cloud forms. The greater the radiation, or the longer the radiation dosage lasts, the bigger the electron cloud.

Electron clouds cannot thermoluminesce by themselves. If crystals were perfect, there would be no thermoluminescence. But crystals have imperfections. They can have impurities locked in their lattice structures, just like the *n* and *p* impurity doping in semiconductors. They can have mechanical structure defects. At higher temperatures, they can have "statistical" defects, caused by thermal agitation. Some of these defects can capture a loose electron. These are called *traps*, and once an electron gets trapped, it is stuck there, at least for the time being.

A trap that has caught an electron is called a *filled trap*. The greater the radiation dosage, the more electrons get knocked loose, and the greater the number of filled traps.

Each trap can only supply so much holding energy to an electron. If we heat the material, the electrons can achieve enough additional thermal energy so that the trap releases the electron. Certain types of traps will also cause the electron to release its own excess energy in the form of light when the release temperature is reached. These traps produce thermoluminescence; they are also closely related to the mechanisms that determine the color of the substance.

Once the electron has released its excess energy, it is free to once again get captured by an ion with a missing electron, removing the effect of the radiation dosage.

To summarize, energy from external radiation increases the energy of some internal electrons and breaks them loose, forming an electron cloud. Some of the electrons get trapped by crystal imperfections. Heating the crystal at a later time releases the extra kinetic energy stored in the trapped electrons and, for certain traps, the excess energy is liberated as light, thereby producing thermoluminescence.

Some traps can very tenaciously hold onto an electron, while others can only retain one weakly. These are called high-energy and low-energy traps. There are usually many more low-energy traps. A slight temperature increase can empty a low-energy trap, while a large temperature increase is needed to empty a high-energy trap. When long, uniform dosage rates are being used, the *equilibrium temperature* is defined as that temperature at which thermal agitation is emptying the traps just as fast as incident radiation is filling them.

Glow Curves

If we take some crystalline substance with imperfections and blast it at a fairly low temperature with nuclear radiation, and then crush the sample and heat it at a constant rate, we would get a light-vs-temperature curve called a *glow curve*. One such curve appears in Fig. 1A. The glow curve has glow peaks that correspond to different energy-level traps that get progressively released as the increasing sample temperature provides more and more thermal energy.

The shape of the glow curve depends upon the material selected, as does the position of the glow peaks and their number. The total area under the glow curve, or the total light produced, is proportional only to the received radiation dosage and nothing else. While the heating rate will affect the height of the glow peaks, it does not affect the total amount of light produced.

If we ran the glow curve over and over again for increasing dosage rates, we would generate a *dosage curve*, such as that shown in Fig. 1B. Dosage is normally expressed in rads. One rad is equal to 100 ergs of absorbed energy per gram of sample. As the figure shows, the total recovered light is proportional to the radiation dosage. With suitable calibration, we can find what the dosage was—simply by measuring the total light produced when the glow curve was generated.

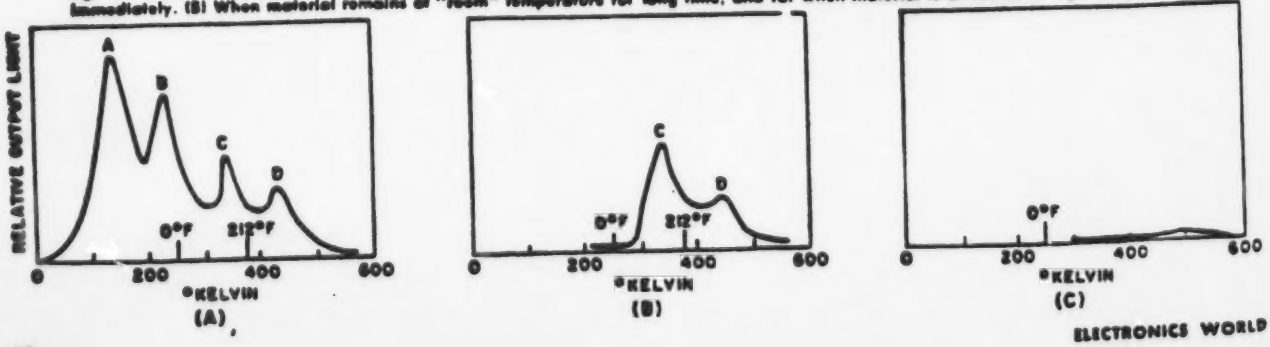
An extreme dosage could fill up all the traps and saturate the material. However, this is usually such an extreme amount of radiation that almost all thermoluminescent measurements are made well down on the dosage curve, retaining a linear relation between dosage and light level.

The output light is shown in relative units. The actual output depends upon how the material is prepared, the number of traps, the optics and photomultiplier in use, and the electronic amplification. Calibration is necessary when a substance is undergoing measurement. By exposing the material to a known radiation dosage, an output light level will be obtained. This level can be compared to a measured output to determine an unknown dosage by simple proportion.

How much light is produced depends upon the material and the dosage. Some materials put out enough thermoluminescence to read a newspaper by for several minutes; others emit light so feebly that elaborate precautions are needed to get meaningful results. Some materials do not thermoluminesce at all.

Table 1 lists some of the more interesting materials, min-

Fig. 2. Glow curves produced (A) when material is irradiated at low temperature and thermoluminescent measurement made immediately. (B) When material remains at "room" temperature for long time, and (C) when material is annealed at high temperature



erals, and chemicals that exhibit thermoluminescence. All we require is that a material have an ordered crystalline structure, or at least a semi-ordered, glass-like structure. It can be either an insulator or a semiconductor, but must not be a conductor. It has to have light-trapping traps, so the material requires either impurities or imperfections in its structure. As the table shows, there are many materials that meet these requirements.

One group of chemical compounds that produces useful thermoluminescence are the *alkali halides*, of which ordinary table salt is a typical member. These have been widely studied. Several alkali halides are used as dosimetry materials in quantitative applications of thermoluminescence.

One popular alkali halide is lithium fluoride. It thermoluminesces brightly, is chemically stable, reasonably nontoxic, and easy to form into bar, rod, disc, or powder. It, along with other dosimetry materials and instruments, is available from companies such as *Controls for Radiation, Inc.*, 130 Alewife Brook Parkway, Cambridge, Mass. 02140 or *Harshaw Chemical Company*, 1945 East 97th St., Cleveland, Ohio 44106. The cost runs $8-$20 per gram, but since only a fraction of a gram is needed per measurement, and since many materials are reuseable, the price per measurement is quite low.

Actually, very pure lithium fluoride does not thermoluminesce very well because there are not enough traps to produce a useful light output. To get around this problem, impurities are introduced purposely to increase substantially the number of traps. These impurities are called *activators*, and are often trace quantities of magnesium, terbium, europium, or other rare-earth elements. By close control of the amount and type of activator, sensitive, stable, and reproducible dosimetry materials are obtained. Further refinements, particularly in controlling which lithium isotopes get into the final material, allow the material to discriminate between different types of atomic radiation. Neutrons are particularly easy to identify with one commercial dosimetry powder.

Important Side Effects

Before we look at how to make a useful thermoluminescence measurement, we have to consider several important side effects. How long the material has remained at what temperature is very important. If we are researching materials, we would purposely irradiate the substance at a low temperature and then run the entire glow curve, possibly getting a glow curve such as the one shown in Fig. 2A. If we are dealing with an archeological ceramic or a Pre-Cambrian rock, it has remained at "room" temperature for many centuries. This, combined with a low and constant dose rate, will cause all the low-energy traps to be emptied eventually, and a glow curve such as the one in Fig. 2B will usually result. Note that all traps lower than "room" temperature have been emptied. There is even a slight chance that traps above this temperature have been slightly emptied. This problem is avoided in geological and archeological dating by using only the highest temperature glow peaks; these are far above the equilibrium temperature and most likely have not been disturbed.

To empty a material of all its previous radiation history, we anneal it by heating. For effective annealing, the material is first heated to a very high temperature for a relatively short time, and then to a moderate temperature for a relatively long time. The two-step process favors emptying both low- and high-energy traps, and a no-light curve of Fig. 2C results. We anneal a material whenever we want to erase its entire dosage history up to the present time.

A second side effect is called *spurious luminescence*. Other factors can make a material emit light. These factors include how it was ground, the pressures it has been subjected to, organic combustion, and chemical activity. Spurious luminescence is a particularly acute problem in archeological

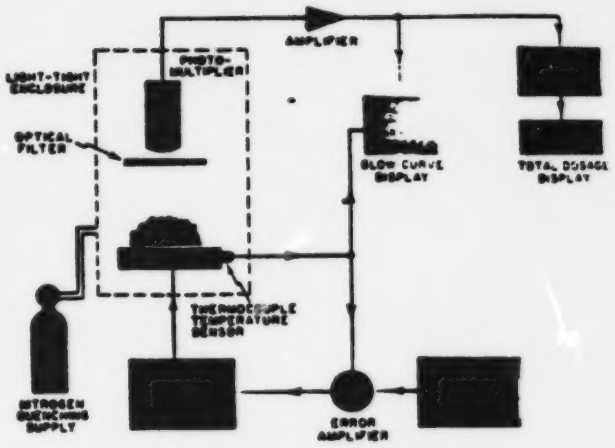


Fig. 3. Instrumentation used in thermoluminescent measurement. Servo-controlled heater assures constant heating.

dating. This is because low dose rates for a relatively short time on a relatively poorly thermoluminescing material result in very low light levels that are easily masked by the spurious effects.

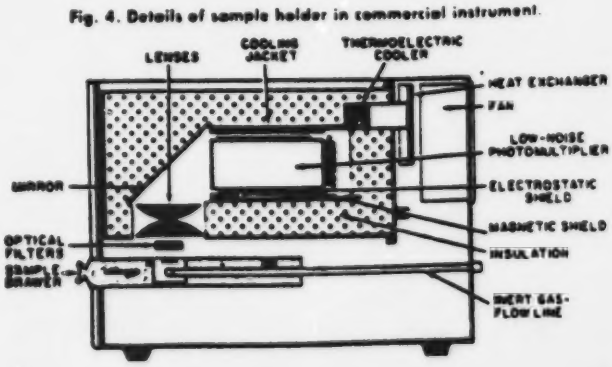
Most of the spurious luminescence is caused by oxygen in the air. We can get rid of most of it by making the measurements in a nitrogen atmosphere. This is called *nitrogen quenching*, and works only if the nitrogen is very pure. Spurious luminescence may be further reduced by a reducing paint near the sample. The reducing paint chemically "grabs" any oxygen remaining on the surface of the material under test.

There are other side effects. Pressure—either from grinding or, in cons gone by, in geological activity—can affect the glow curves. The sample size and its preparation are critical for optimum results. The heating rate is also critical, for heating too slowly does not produce enough instantaneous light, and heating too fast skews the glow peaks and makes them hard to interpret. Rates of 1° C/second to 25° C second are often used in routine dosimetry measurements.

Instrumentation Employed

To make a thermoluminescence measurement, we have to heat a sample at a constant rate and observe the light produced. A system for doing this is shown in Fig. 3. The sample typically weighs around 30 milligrams and is sometimes processed to form a thin disc-shaped spot, perhaps half an inch across. To get precise temperature control and a constant rate of rise of temperature, servo feedback is used. We start with a ramp generator that controls a proportional power controller, usually using an SCR or a triac. This drives the sample heater. A temperature sensor on the heater produces a feedback voltage that is compared against the ramp generator's output; any differences alter the heating power applied to linearize the results.

Fig. 4. Details of sample holder in commercial instrument.



A photomultiplier observes the sample and produces an output proportional to the thermoluminescence. The enclosure surrounding the sample, heater, and photomultiplier must be light-tight, and is normally flushed with nitrogen from a tank supply to eliminate any spurious luminescence.

The photomultiplier output is amplified and, together with a signal from the temperature sensor, is fed to an X-Y recorder that generates the glow curve in graphic form. The photomultiplier output also goes to a charge integrator that calculates the total light produced, digitizes it, and presents the total dosage on a digital readout.

A heater and photomultiplier assembly are shown in Fig. 4. It has several refinements over the basic measuring process just described. The light path is bent to put the photomultiplier outside of any direct infrared radiation from the sample heater. Lenses and a mirror bend the light suitably but are largely opaque to the infrared radiation. An optical filter also enhances the thermoluminescence signal at the expense of spurious and infrared background. The photomultiplier is a very-low-noise type. It is shielded both magnetically and electrostatically to prevent internal light and noise from being generated. The photomultiplier is cooled with a thermoelectric cooler which keeps the background noise low and uniform, regardless of whether the measurement is at the high end or the low end of the glow curve; the entire assembly is suitably insulated.

A complete instrument is shown in the photo. This is the *Harshaw Chemical* Model 2000 thermoluminescence analyzer. The left unit contains the sample drawer, heater, and photomultiplier, while the right one contains the integrator and dosage readout. Other features include a calibration light source, a sample vibrator and dispenser, and direct-temperature readout. An additional X-Y plotter is needed if a glow curve is to be obtained. If quenching is desired, an external connection must be made to a nitrogen tank.

Nuclear & Medical Applications

One application of thermoluminescence is in basic solid-state research. Crystals with slight impurities are the keystone of today's solid-state materials. Basic thermoluminescence studies can add new knowledge to this all-important field.

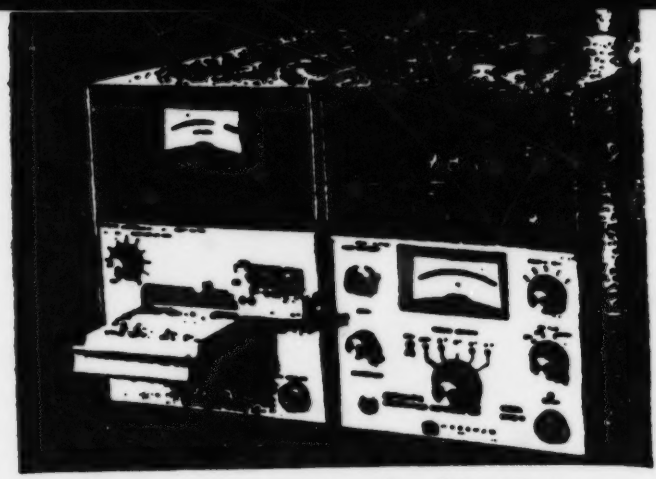
Thermoluminescence can be a much more sensitive radiation indicator than either a Geiger or a scintillation counter, as it responds to the total dosage through time instead of making an instantaneous or short-term measurement.

For nuclear prospecting and for radioactive deposit mapping, thermoluminescence can be a highly sensitive radiation indicator. Rock samples near a suspected radioactive source have dosage measurements made on them; results of the dosage measurements plot extent and value of the deposit.

To protect people working around a nuclear reactor or other dangerous radioactive source, badges using lithium fluoride are often worn. Special finger rings are also used where people might expose only their hands to radiation hazards. These badges and rings are annealed before being issued; the resultant thermoluminescence as a result of use indicates the dosage the person wearing the badge has absorbed. Personal dosage histories are kept easily and accurately this way. Compared to the film-badge technique, thermoluminescence is more accurate and less dose-sh pendent at low dosage rates.

A similar measurement was recently applied to roof tiles recovered from Hiroshima, plotting the extent and strength of the atomic-bomb radiation.

Much of today's cancer and [illegible] research is centered around radioactive treatment. Thermoluminescence provides an attractive method of measuring the actual dosage absorbed. To do this, annealed lithium fluoride or another one of the dosimetry materials is encased in inert Teflon in either a pill or a probe shape. The dosimeter built this way is either implanted or swallowed and later recovered after irradiation or other radioactive treatment. The thermoluminescence gives an accurate account of the total dosage.



A complete thermoluminescence analyzer. Unit at left contains sample drawer, heater, and photomultiplier; the unit at the right contains the integrator and the digital readout.

Uses in Geology & Archeology

There are many geological uses for thermoluminescence. By comparing the total thermoluminescence to date of two different rocks, the relative age of one with respect to the other can often be determined. By making certain assumptions as to what the dose rate was, an absolute dating scale may also be obtained. To do this, the sources of radioactivity affecting the sample must be known, as must the sample's susceptance to thermoluminescent activity. Given these two factors, the absolute age is readily determined.

Subtle changes in equilibrium temperature of a material can give profound clues of past climatic activity. Thermoluminescence tests run in Antarctica have placed a bound upon how long the area was cold.

The moon is one big thermoluminescence machine. For fourteen days, the hot surface temperature anneals all the surface materials. For fourteen more days, when the surface is around on the dark side, high-energy particles from the solar wind fill the traps on surface thermoluminescent materials. As the surface comes around to the sunny side again, it is heated at a fairly constant rate and provides thermoluminescence for a few hours. Astrogeologists are able to draw certain conclusions about meteors and surface materials on the basis of this evidence.

The newest application of thermoluminescence is in archeology. It can provide absolute calendric dating of ancient pottery. When a pot is fired, it is also conveniently annealed, and its past radiation history is erased. From the firing on, the slight thorium and uranium impurities in the clay emit high-energy particles which fill the traps with electrons. To find the age of the pot, a sample is crushed, separated into optimum size particles, and its thermoluminescence is measured. The amount of new dosage is found which produces the same amount of thermoluminescence by annealing and the reradiating with a known dose. Finally, the particle emanation caused by the uranium and thorium impurities is measured. Knowing the dose rate and total dosage, a simple division gives the age of the ceramic.

Today, this technique is just beginning to be put to use. There are important advantages of thermoluminescence over the popular carbon-14 dating technique in that the dating is applied to the artifact itself, the pottery is widely available for testing, and sample contamination and dosage uniformity are not as significant. Other archeological applications include the evaluation of pre-pottery stone boilers, cave temperatures, firepits, and kiln temperatures. The technique is also a powerful tool for identifying fake "ancient" pottery. ▲

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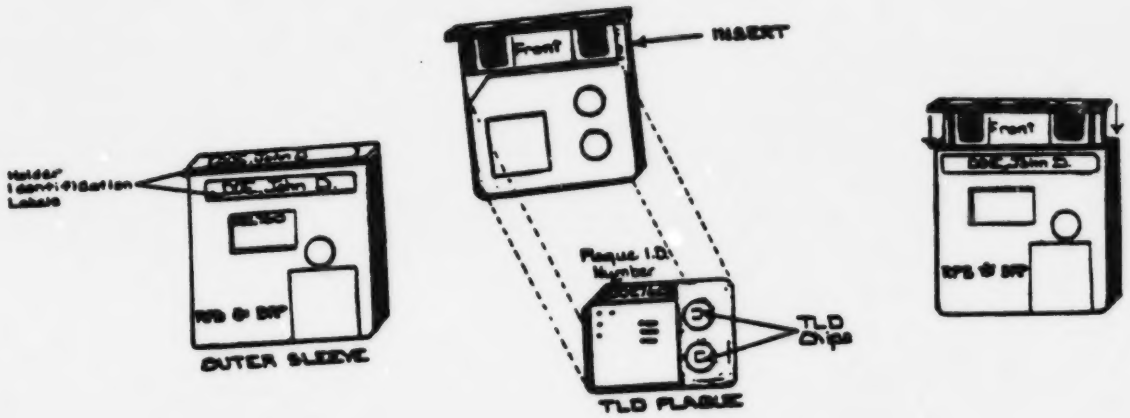
Ziff Davis

THERMOLUMINESCENT DOSIMETRY SERVICE (TLD SERVICE)



A. Terminology:

The dosimeter consists of an aluminum TLD plaque and a plaque holder. Each is an integral part of the dosimeter. Both must be used together.

Holder (Plaque Holder) - consists of a sleeve with a clip and an insert.

Plaque (Dosimeter Plaque) - consists of an aluminum plaque containing two radiation-sensitive elements, numbered identification, and punched tape identification.

Dosimeter - consists of a plaque in a plaque holder.

1. Dosimeter Plaque

The dosimeter plaque consists of an aluminum planchet with a printed label, binary-coded tape for identification, and a pair of LiF-100 chips, (the radiation-sensitive elements). Each dosimeter is uniquely and

permanently numbered with a "numeric identification label" for visual identification by the subscriber and by a "binary-coded punched tape" for automated identification. The pair of chips are each 1/8" square but differ in thickness, one being 0.015" and the other 0.035". The thickness differences combined with the aluminum foils in the holder serve to provide a means of differentiating body and skin doses. One corner of the dosimeter plaque is removed to ensure proper orientation in the holder and in the read-out instrument. NO ATTEMPTS SHOULD BE MADE TO REMOVE THE TAPE OR THE CHIPS.

The plaque number which appears on the label is to be used only as a means of identifying individual dosimeter plaques. It bears no personal significance to the wearer, other than being his assigned dosimeter plaque for the current wearing period, and contains no encoded wearing period information. It is highly unlikely that an individual will wear the same dosimeter plaque in subsequent monitoring periods. Please do not enscribe any further identification or markings on the plaque.

2. Holder

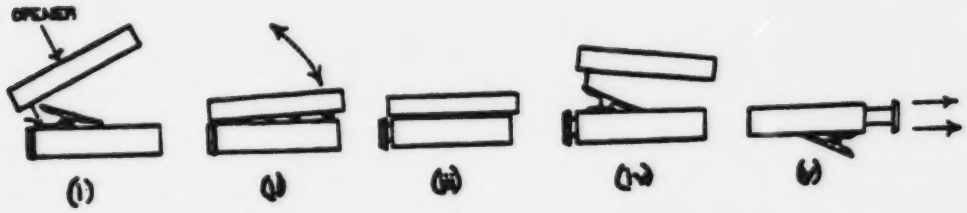
The holder is designed to reduce the incidence of contamination of dosimeter plaques and to provide a relatively tamper-proof system by being completely closed. The holder is in two parts, an outer sleeve and an insert.

The insert has a recessed area designed to accept the plaque in only one position. There is an embossment on the insert indicating the correct orientation for insertion in the outer sleeve.

The outer section of the holder has the following features: a wearing clip affixed to the holder back; a transparent window through which the plaque identification is visible when the insert is correctly inserted; two aluminum foils for penetrating dose estimation (one each on the front and back positioned directly over the thick chip); and two holes in the back for insertion of the unlocking tool pins. When the dosimeter is properly assembled, the identification number is clearly visible through the transparent holder window.

3. Opening Tool

The opening tool is the mechanism used to unlock the holder insert from the sleeve into which it is placed. The pins of the opening tool are inserted into the two holes in the holder back and slight pressure is applied with a rocking motion. This action depresses the locking tabs allowing withdrawal of the insert containing the dosimeter plaque. The exact opening operation is illustrated by the following diagrams and is explained as follows:



i) Insert the pins of the opening tool into the two small holes in the holder back so that the opening tool surrounds the clip.

ii) Grasp the combination between the thumb and forefinger on each hand, with the thumbs in contact with the opening tool.

iii) Apply slight pressure with the thumbs and rock the opening tool forward and back once or twice. This has the action of depressing the locking tabs and pushing the insert out slightly.

iv) Remove the opening tool, turn badge over so that the front is now up and pull the insert out of the sleeve.

v) Remove the dosimeter plaque by pushing through the bottom of the hole in the insert.

iv) To load the dosimeter, place the plaque into the insert, and slide the insert into the sleeve ensuring that the identification faces the front. <u>Check window for identification number.</u>

B. Wearing Periods:

Each dosimeter should be worn for the specified wearing period. Wearing periods commence on 1st or 15th of the month. See your specific name list for change dates.

C. Group Identification:

Each group is identified by a group number along with a prefix code to identify the series of the group. Please refer to this complete group number in any correspondence with respect to the TLD monitoring service. e.g. (A)1234.

D. Holder Identification:

The Radiation Dosimetry Division will supply those groups requesting them, with approved labels for user identification purposes. These are to be affixed to the holder in only one of two places. Any other positions may be detrimental to correct dose interpretation, while other means of inscription may cause damage to the holder for which the group will be charged. The approved locations are indicated in the drawings of the holder components (see page 1).

E. Plaque Identification:

There is no provision for enscribing an individual's name on the dosimeter plaque. Thus, once the plaque has been placed in the holder the wearer can identify it by the label affixed to the holder or by reference to the name list and the dosimeter number visible through the transparent window in the holder.

It is, therefore, important that the name list be maintained and updated whenever a film is assigned so that it confirms the dosimeter wearer.

Name lists must be returned with the corresponding dosimeter plaques at the end of the scheduled wearing period. A photo-copy of the name list should be kept for a group's records.

Any returned dosimeter plaque must be properly identified or it will be reported as "VISITOR" and no accumulated dose records kept. Proper identification consists of one of the following:

i) A pre-printed name on the name list.

ii) A hand-entered name beside the plaque number and Part C of the name list fully completed.

iii) NOT USED entered beside the plaque number for any plaques which are not assigned or if pre-assigned, are not used.

F. Wearing Position:

Each personal body dosimeter must be worn at the chest or waist position. If applicable, it should be worn under the lead apron. If required, additional separate dosimeters may be used for extremity monitoring outside lead aprons.

G. Storage of Dosimeters (Control Dosimeter where issued).

The purpose of the control dosimeter is to detect and measure any exposure of the personal dosimeter plaques during transit to and from a group (i.e. in the mail) and while in storage at a group where there is high background radiation.

All plaques should be kept in the mailing box and stored until the scheduled change date. Avoid any direct exposure of the plaques to light or a dusty environment while they are outside the holder. Once in the holder, they should be stored along with the control dosimeter when they are not being worn (i.e. before commencement of the scheduled period, overnight, weekends, etc.).

The control dosimeter must NOT be used as a personal dosimeter except for emergency situations. It must NOT be used as a test or area dosimeter.

H. Name List:

Enclosed with your dosimeters each period will be a corresponding period name list, containing an alphabetical listing of the current individuals for your group and their assigned plaque number for that period. Plaques should be issued as outlined in the name list instructions. As they do not carry an individual's personal identification, it is very important that the name list indicate the wearer of the dosimeter and that "Part C" of the name list be correctly completed when the wearers name is not pre-printed on the name list.

Each period when issuing plaques, Section A should be reviewed and updated if necessary. Parts B and C need only be completed when applicable.

Retain a copy of each returned name list as the originals are not kept by the Radiation Dosimetry Division after processing.

I. Return of Plaques:

1. Normal processing and reporting

Plaques should only be used for their scheduled period. They all should be returned together with their completed name list at the end of the scheduled period (1st or 15th), whether or not they have been used. If all plaques cannot be returned together, return your groups name list with your first shipment of plaques so that corrections may be made if applicable.

The plaques should be secured with elastic bands, then placed in the specially designed return box with the pre-printed RPB address clearly visible on the front of the box, and the box flap sealed with the "FILMS - Handle with Care" label. For quick identification of your plaques on their receipt in Ottawa, please enter your group number on the outside of the box, in the designated area. Your cooperation in this regard will help us provide you with quicker service.

2. Emergency processing and reporting

Any plaques which require immediate processing and reporting should be forwarded by registered air mail along with an explanatory letter, to the following address:

Radiation Dosimetry Division
Department of National Health and Welfare
Radiation Protection Bureau
Brookfield Road
OTTAWA, Ontario
K1A 1C1

A detailed report explaining the full details of the exposure situation and significance should be forwarded as soon as possible after returning the dosimeters.

J. Changes in Plaque and/or Holder Requirements:

Each period your current plaque total will be printed on your name list. If changes in the plaque and/or holder totals are required, please complete Section B. Ensure you include the control plaque in any stated plaque total. If previous letters, telephone calls, etc., have been forwarded requesting changes in requirements, the new totals should be verified in Section B in the subsequent name list.

K. Changes in Addresses:

Changes or corrections of addresses should be made by letter. Please identify your group number and provide a complete address including suite number if applicable and postal code number.

L. Cancellation of Service:

All requests for cancellation of service must be made by letter. Please identify your group code number to ensure correct actioning.

APPENDIX C

REPORTING SHEETS FOR PARTICIPANTS

REPORTING SHEET FOR VRADIUM CONCENTRATE

MONTH:
YEAR:

NAME:
DESIGNATION:

COMPANY:
LOCATION:

BADGE NO: 1-MONTH:
3-MONTH:

CAB:
AREA:

DATE	NO. OF TRIPS	TIME IN VEHICLE	LOADING TIME	MATERIAL HANDLED: BOOMS	SLURRY	RAFF.	TRAILER: 36-FT	45-FT	CONT.	TANK	TRACTOR: SLEEP	REG.	BOOMS: SIDE	BOOM	DEVIATIONS FROM NORMAL ROUTINE	OTHER COMMENTS
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PLEASE EXCHANGE YOUR BADGE AT THE END OF THE MONTH

REPORTING SHEET FOR EXCLUSIVE USE CONTAINERS

MONTH: NAME: COMPANY: BADGE NO: 1-MONTH:
YEAR: DESIGNATION: LOCATION: 3-MONTH:

DATE	TRIP YES	TRIP NO	TIME IN VEHICLE	TRUCK TYPE SLEEPER	TRUCK TYPE REG	NO. OF CONTAINERS COBALT	NO. OF CONTAINERS NO3	NO. OF CONTAINERS U76	CONTAINERS FULL	CONTAINERS EMPTY	DEVIATIONS FROM NORMAL ROUTINE
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2											
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REPORTING SHEET FOR INDUSTRIAL ISOTOPES

MONTH:
YEAR:

NAME:
DESIGNATION:

COMPANY:
LOCATION:

BADGE NO: 1-MONTH:
3-MONTH:

CAB:
AREA:

DATE	NO. OF TRIPS	TIME IN VEHICLE	LOADING TIME	UNLOADING TIME	TRANSPORT ISOTOPES SHIPPED	TRAILER 26'	TRAILER 45'	TRAILER OTHER:	LOAD TL	LOAD LTL	LOAD POSITION F	LOAD POSITION	LOAD POSITION	LOAD POSITION B	DEVIATIONS FROM NORMAL ROUTINE	OTHER COMMENTS
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PLEASE EXCHANGE YOUR BADGE AT THE END OF THE MONTH

REPORTING SHEET FOR MEDICAL ISOTOPES

MONTH:
YEAR:

FOR:
DESIGNATION:

COMPANY:
LOCATION:

BADGE NO: 1-MONTH:
3-MONTH:

CAR:
AREA:

DATE	NO. OF TRIPS	TIME IN VEHICLE	LOADING TIME	UNLOADING TIME	PACKAGES HANDLED I	II	III	VEHICLE TYPE ECON.	LER.	1-T	5-T	2A'	40'	LOAD BTN.	E.USE	LTL	LOAD POSITION F			B	DEVIATIONS FROM NORMAL ROUTINE	OTHER COMMENTS
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PLEASE EXCHANGE YOUR BADGE AT THE END OF THE MONTH

APPENDIX D

SUPPORTING DATA FOR CORRELATIONS BETWEEN DOSE RECEIVED AND MATERIALS HANDLED

APPENDIX D

In this appendix, supporting data for the correlations between dose reported and materials handled (or handling time) as discussed in Section 8, is presented.

The data was analyzed using standard statistical procedures as outlined in "Biostatistical Analysis", 2nd Edition, Prentice-Hall, by Jerrold Zar, 1984. Linear regression analyses were performed using a least squares procedure. Results of these regressions, reported as intercept, slope, and the coefficient of determination (r^2) are shown in Table 8.1.

The 95% confidence interval was developed for the entire range of each best fit line by calculating the confidence interval for each estimated dose value (Y). This was calculated from the following equation:

$$\text{confidence interval} = Y_i \pm t_{0.05(2),n-2}\, S_Y \qquad \text{(D-1)}$$

where Y_i = estimated dose from the regression fit

$t_{0.05(2),n-2}$ = value of the Student t distribution, two-tailed, with degree of confidence of 95% and n-2 degrees of freedom

n = number of data points

S_Y = standard error as given by;

$$S_Y = (S_{YX})^2\ (1/n + (X_i - X_{avg})^2/\text{sum}(x^2))^{1/2} \qquad \text{(D-2)}$$

where X_i = x value associated with dose Y_i

X_{avg} = average value of X

and

$$\text{sum}(x^2) = \text{sum}(X_i^2) - \text{sum}(X_i)^2/n \qquad \text{(D-3)}$$

and

S_{YX} is the standard error of variance.

The latter is calculated by determining: 1) the total source of variance and 2) the linear regression source of variance as follows;

1) Total Source of Variance (total SS)

$$\text{total SS} = \text{sum}(y^2) \tag{D-4}$$

where

$$\text{sum}(y^2) = \text{sum}(Y_i^2) - \text{sum}(Y_i)^2/n \tag{D-5}$$

2) Linear Regression Source of Variance (reg SS)

$$\text{reg SS} = \text{sum}(xy)^2/\text{sum}(x^2) \tag{D-6}$$

where

$\text{sum}(x^2)$ = equation (D-3)

$$\text{sum}(xy) = \text{sum}(X_iY_i) - \text{sum}(X_i)\text{sum}(Y_i)/n \tag{D-7}$$

The standard error of variance, S_{YX} is then calculated from;

$$S_{YX} = ((\text{total SS} - \text{reg SS})/(n-2))^{1/2} \tag{D-8}$$

This value is substituted into equation D-2, along with $\text{sum}(x^2)$ (equation D-3) and an X_i value to calculate S_Y. This value of S_Y, is substituted into equation D-1, along with the Student t value (from standard statistical tables) and the confidence interval calculated for that Y_i. This is repeated for a number of Y values to develop the 95%

confidence band. This range was plotted on each correlation as upper and lower 95% confidence limits.

As part of the regression analysis, the validity of each correlation was also tested. This was accomplished on the basis of determining if the hypothesis of a zero correlation (i.e. the slope of the correlation was not statistically different from zero) was true. This was tested at both 95% and 99% confidence levels. If the hypothesis is <u>not</u> accepted, the assumption of no correlation is not correct at that confidence level. Therefore while it is not possible to statistically prove that a correlation exists, it is possible to state with a given confidence, that the assumption of no correlation is untrue. The procedure for testing this hypothesis is based on the Student t distribution (t). The calculated t value is determined from the following:

$$t_{calc} = \text{slope}/s_b \qquad \text{(D-9)}$$

where

slope is calculated from the regression analysis

and $s_b = ((S_{YX})^2/\text{sum}(x^2))^{1/2}$ (D-10)

where $(S_{YX})^2$ is calculated from equation (D-8)

and $\text{sum}(x^2)$ is calculated from equation (D-3).

This calculated t value is compared to the critical test value of $t_{0.05(2),n-2}$ (95% confidence level with n-2 degrees of freedom) taken from standard Student t distribution tables. If the calculated t is greater than $t_{0.05(2),n-2}$ then the hypothesis of zero correlation is not accepted. Using this procedure it is possible to calculate a critical r value. Similarly, experimental r values greater than the critical r value indicate that the "null hypothesis" is not accepted. The results of this "null hypothesis" testing are shown as "accepted" or "not accepted" in Table 8.1. "Accepted" in this table indicates

that the correlation coefficient (r) was less than the critical r value given for a particular confidence level, and the assumption of no correlation is true. Conversely, "not accepted" indicates that the correlation coefficient was greater than the critical value and the assumption of no correlation is not accepted.

A) Figure 8-1

As indicated, Figure 8-1 is a plot of reported dose vs the number of packages of medical isotopes handled in a six-month period. In reviewing this figure, it can be seen that the seven data points used in the development of this correlation fall within the 95% confidence limits. Supporting data for this correlation is given in Table D-1 at the back of this appendix. As indicated in this table and as shown on Table 8.1, the coefficient of determination (r^2) for this correlation was found to be 0.92813. With a correlation coefficient value of 0.963, the null hypothesis is not accepted at even the 99% confidence level.

The equation for the best fit line on this correlation is given as follows:

REPORTED DOSE (in mSV) = 0.00187 x (no. of packages handled in 6 mon.) - 0.34125

B) Figure 8-2

Figure 8-2 is a plot of reported dose vs driving time while hauling UF_6 cylinders. As noted in the main text, only two of the participants in the study handled these materials. Since inexplicably high doses were reported for one of these drivers during the first portion of the monitoring period, only three data points were used in the development of this correlation. Since the line representing the lower 95% confidence limits falls below the zero dose line (thus indicating

negative doses which are not possible), it was not included in the plot.

Supporting data for this correlation is found in Table D-2 and the pertinent information is provided in Table 8.1. As indicated in these tables, although the correlation coefficient was high (0.985), the null hypothesis was accepted for both the 95% and 99% confidence levels due to the limited number of data points available. (For the null hypothesis not to be accepted at the 99% confidence level, a coefficient of 1.000 is required.)

The equation for the best fit line for this correlation is given as follows:

REPORTED DOSE (in mSV) = 0.00126 x (driving time in hours) + 0.05658

C) Figure 8-3

As indicated, Figure 8-3 is a plot of reported dose vs the number of waste containers hauled. Since there was only one participant in the study who hauled this type of material, only two data points were available to produce a correlation. Because of the limited data, it was not possible to produce 95% confidence limits nor carry out the null hypothesis testing. It is apparent, however, from the low doses reported, that the individual is not likely to exceed the maximum annual limit of 5 mSv set for members of the general public.

Supporting data for this correlation is provided in Table D-3, pertinent data is given in Table 8.1.

The equation for the best fit line on this correlation is given as follows:

REPORTED DOSE (in mSv) = 0.00125 x (number of waste containers hauled) + 0.01875

D) Figure D-1

Figure D-1 is similar to Figure 8-1, except that it is a plot of reported dose vs the total number of packages of medical isotopes handled in a three-month period rather than in a six-month period. Although this correlation was based on more data points (fourteen as opposed to seven), the reverse trends discussed in the main text, result in more scatter of the data points and (as evident from Table 8.1) in an r^2 value of only 0.66721. The null hypothesis, however, is not accepted at either the 95% or 99% confidence levels. Supporting data for this correlation is found in Table D-4.

The equation for the best fit line on this correlation is given by the following:

REPORTED DOSE (in mSV) = 0.00187 x (no. of packages handled in 3 mon.) - 0.14028

E) Figure D-2

Figure D-2 is similar to the plot on Figure 8-1 except that the number of Category I packages handled in the six-month period has not been included in this correlation. As discussed in the main text, these packages emit very low levels of radiation. By omitting them, they would not bias the correlation should their ratio to the number of Category II and III packages be disproportionately high. Supporting data for this correlation is provide in Tables 8.1 and D-5. As

Figure D-1

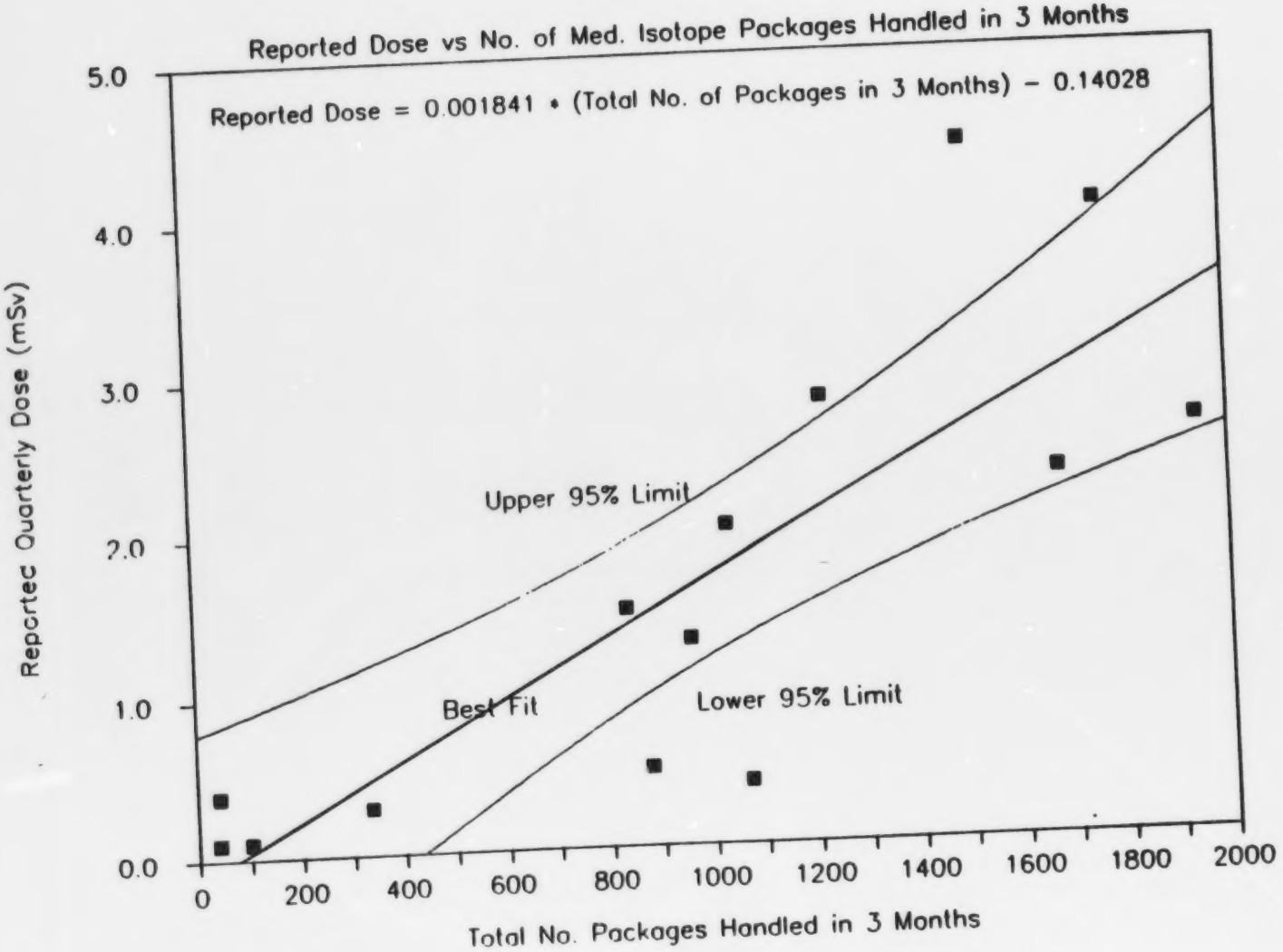
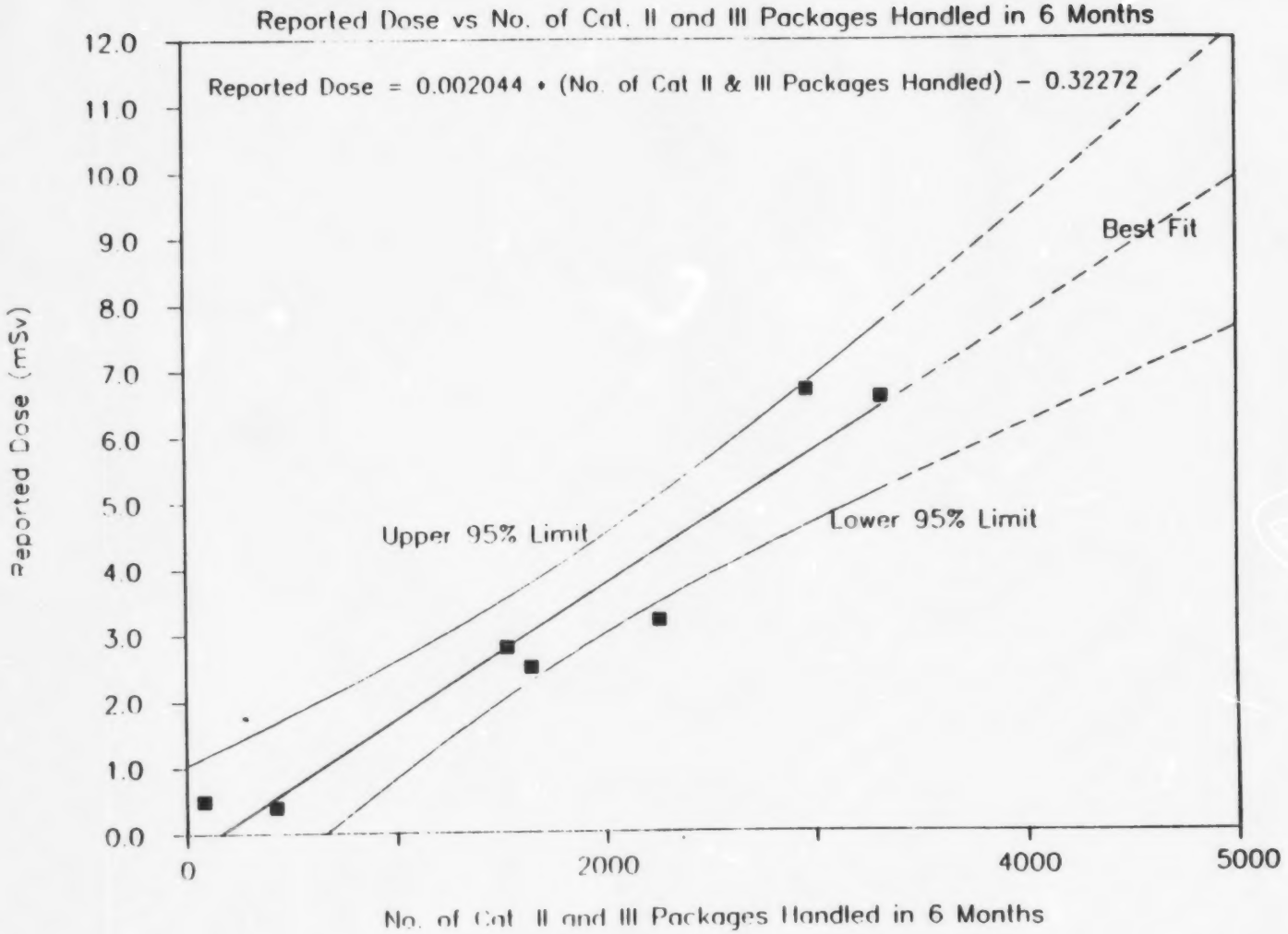

Reported Dose vs No. of Med. Isotope Packages Handled in 3 Months
Reported Dose = 0.001841 * (Total No. of Packages in 3 Months) - 0.14028
Upper 95% Limit
Best Fit
Lower 95% Limit
Reported Quarterly Dose (mSv)
Total No. Packages Handled in 3 Months
5.0
4.0
3.0
2.0
1.0
0.0
0
200
400
600
800
1000
1200
1400
1600
1800
2000

Figure D-2


Reported Dose vs No. of Cat. II and III Packages Handled in 6 Months
Reported Dose = 0.002044 • (No. of Cat II & III Packages Handled) – 0.32272
Best Fit
Upper 95% Limit
Lower 95% Limit
Reported Dose (mSv)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
2000
4000
5000
No. of Cat II and III Packages Handled in 6 Months

indicated in these tables, the null hypothesis for was not accepted at either confidence level.

The equation for best fit line on this correlation is given by the following:

REPORTED DOSE (in mSV) = 0.00204 x (no. of Cat II & III packages handled in 3 mon.) - 0.32272

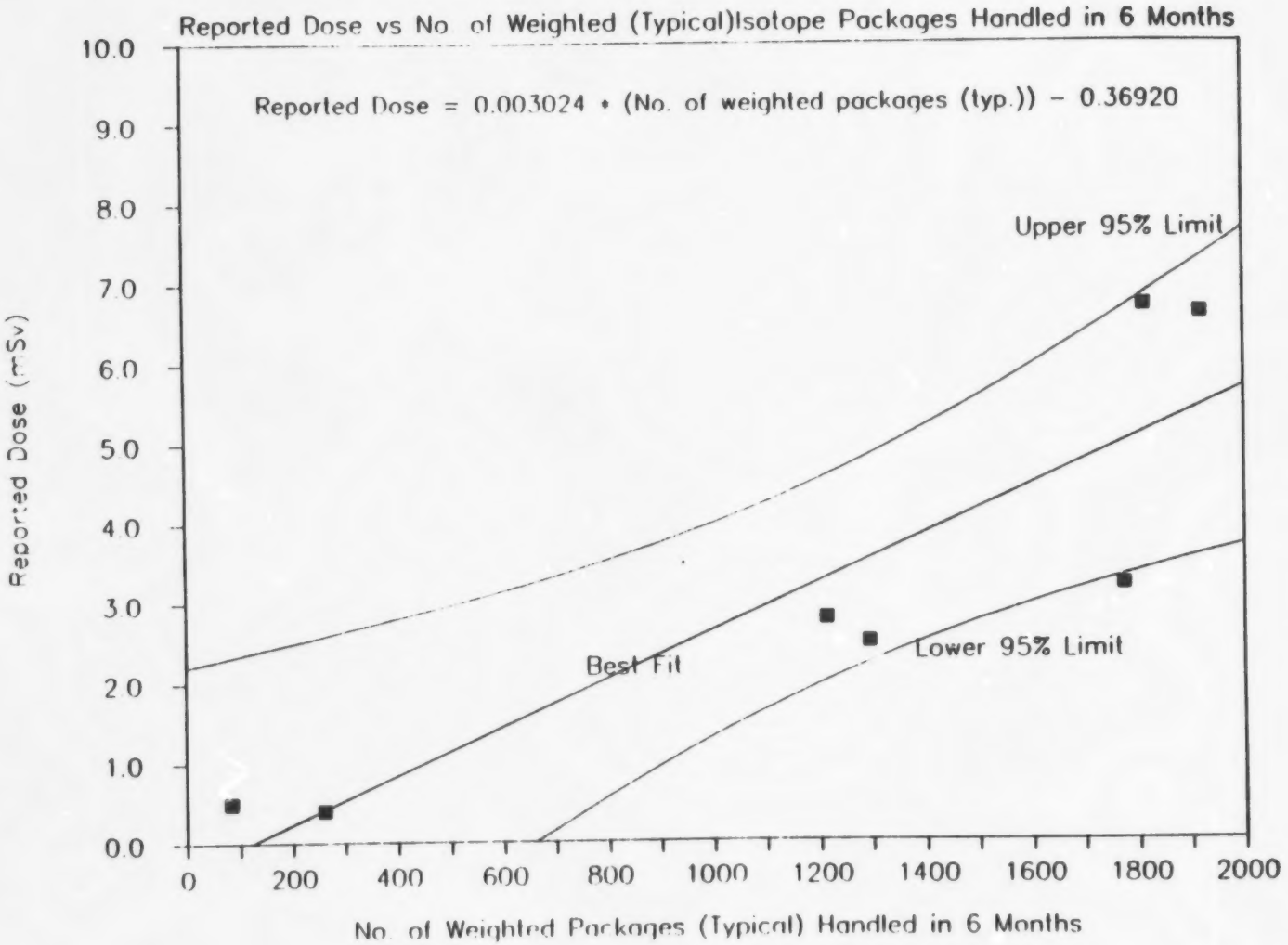
F) Figure D-3A

Figure D-3A is similar to Figure 8-1 except that the number of packages handled in the six-month period were "weighted" according to their transport index (T.I.). This correlation was developed in order to try to produce a relationship that is independent of the ratio of the number of Category I, II and III packages handled. In reviewing the data for one of the participating depots, it was noted that typical Category II packages had T.I. values of about 0.3 and Category III packages had values of about 1.2. Since no T.I. values are given for Category I packages, a value of 0.05 was assigned. Thus the weighted number of packages was determined as follows:

Weighted no. of packages = 0.05 (no. of Cat. I packages) +
0.3 (no. of Cat. II packages) +
1.2 (no. of Cat. III packages)

Supporting data for this correlation is provided in Table D-6 and the pertinent data is summarized in Table 8.1. As indicated, the r^2 value for this correlation is only 0.77720 but the null hypothesis is not accepted at either the 95% or 99% confidence levels.

Figure D-3A


Reported Dose vs No. of Weighted (Typical)Isotope Packages Handled in 6 Months
Reported Dose = 0.003024 * (No. of weighted packages (typ.)) - 0.36920
Upper 95% Limit
Best Fit
Lower 95% Limit
Reported Dose (mSv)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
No. of Weighted Packages (Typical) Handled in 6 Months

The equation for the best fit line on this correlation is given by the following:

REPORTED DOSE (in mSv) = 0.00302 x [weighted (typical) no. of packages handled in 6 months] - 0.36920

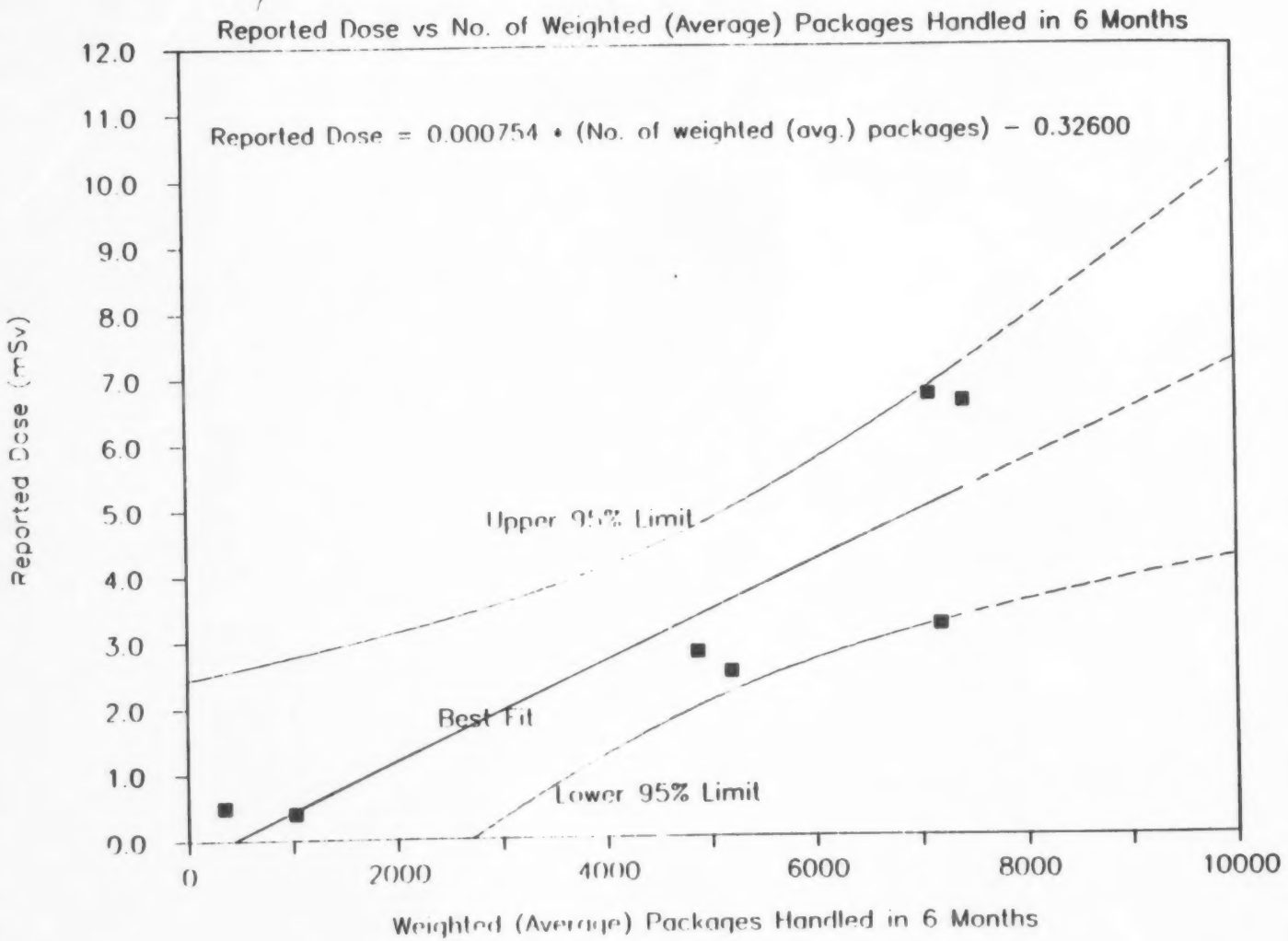
G) Figure D-3B

Figure D-3B is similar to Figure D-3A and was also produced with weighted numbers except that mid point values for the T.I.'s of 0.55 and 5.5 were used as factors for the Category II and III packages, respectively. Thus the weighted number of packages was determined as follows:

Weighted no. of packages = 0.05 (no. of Cat. I packages) +
0.55 (no. of Cat. II packages) +
5.5 (no. of Cat. III packages)

Supporting data for this correlation is provided in Table D-7 and the pertinent data is summarized in Table 8.1. As indicated, the r^2 value for this correlation is 0.74634 and the null hypothesis was not accepted for the 95% confidence limits only.

Figure D-3B


Reported Dose vs No. of Weighted (Average) Packages Handled in 6 Months
Reported Dose = 0.000754 • (No. of weighted (avg.) packages) – 0.32600
Upper 95% Limit
Best Fit
Lower 95% Limit
Reported Dose (mSv)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
2000
4000
6000
8000
10000
Weighted (Average) Packages Handled in 6 Months

The equation for the best fit line on this correlation is given by the following:

REPORTED DOSE (in mSV) = 0.00075 x [weighted (average) no. of packages handled in 6 months] - 0.32600

H) Summary

Figures 8-1, 8-2, and 8-3 are correlations developed to relate reported dose to personnel handling medical isotopes, UF_6 cylinders and radioactive waste containers, respectively. Due to the significance of the doses reported for personnel handling medical isotopes, the correlations shown of Figures D-1, D-2, D-3A and D-3B were also developed for personnel handling these materials.

From the above discussions, it is apparent that of all the correlations pertaining to handlers of medical isotopes, the one shown on Figure 8-1 is the most appropriate for estimating doses since it results in the largest r^2 value, utilizes all categories of packages, and is straightforward in that no factors are involved. Since this correlation addresses all those who carry packages, it is not limited to any particular job type such as driver, sorter or supervisor. It should also be noted that the correlation shown on Figure D-2 could be also be used to estimate doses. The coefficients are nearly as large as those for Figure 8-1 and since it does not include Category I packages, any bias presented by these low-level materials is eliminated.

In addition to those discussed above, a number of other correlations between dose reported and such factors as travel time and loading/unloading times for handlers of medical isotopes were attempted and assessed but these proved to be less satisfactory than those described above.

Table D-1
Statistical Data Used to Develop the Correlation Shown on Figure 8-1

X	X2	Y	Y2	XY
81	6561	0.5	0.25	40.5
437	190969	0.4	0.16	174.8
1798	3232804	2.8	7.84	5034.4
1913	3659569	2.5	6.25	4782.5
2290	5244100	3.2	10.24	7328
3174	10074276	6.7	44.89	21265.8
3697	13667809	6.6	43.56	24400.2

Regression Summary Output:	
Intercept	-0.34125
r2	0.928125
No. of Observations (n)	7
Degrees of Freedom (n-2)	5
slope	0.001873

n	7	Deg.free	5
sumX	13390		
sumX2	36076088		
sumx2	10462930	totalSS	39.57714
sumY	22.7	reg SS	36.73256
sumY2	113.19		
sumy2	39.57714	Residual	0.568916
sumXY	63026.2		
sumxy	19604.34	r2	0.928125

b(slope)	0.001873
Xave	1912.857
Yave	3.242857
intercept	-0.34125
sb	0.000233

Regression Significance t test - 95%
Ho = no correlation

t	8.035288
t0.5,2.5	2.571

t is greater than t0.05

reject Ho

Regression Significance t test - 99%
Ho = no correlation

t	8.035288
t0.01,2.5	4.032

t is greater than t0.01

reject Ho

Legend	
X	total packages handled in 6 months
Y	reported dose
X2	X times X
Y2	Y times Y
XY	X times Y
n	number of points
sumX	sum of all X values
sumX2	sum of all X times X values
sumx2	equation D-3
sumY	sum of all Y values
sumY2	sum of all Y times Y values
sumXY	sum of all X times Y values
sumxy	equation D-7
b	slope of regression line
Xave	average value of X
Yave	average value of Y
intercept	intercept of regression line
totalSS	equation D-4
regSS	equation D-6
residual	totalSS minus regSS
sb	equation D-10
t	calc. t value equation D-9
t0.01,2.5	value from student t dist. (99%)
t0.05,2.5	value from student t dist. (95%)

Table D-2
Statistical Data Used to Develop the Correlation Shown on Figure 8-2

X	X2	Y	Y2	XY
160	25600	0.2	0.04	32
220	48400	0.4	0.16	88
675	455625	0.9	0.81	607.5

Regression Summary Output:	
Intercept	0.056582
r2	0.969924
No. of Observations (n)	3
Degrees of Freedom (n-2)	1
slope	0.001260

n	3	deg.of.free	1
sumX	1055		
sumX2	529625		
sumx2	158616.6	totalSS	0.26
sumY	1.5	regressSS	0.252180
sumY2	1.01		
sumy2	0.26	Residual	0.007819
sumXY	727.5		
sumxy	200	r2	0.969924

b(slope)	0.001260
Xave	351.6666
Yave	0.5
intercept	0.056582
sb	0.000222

Regression Significance t test - 95%
Ho = no correlation

t	5.678855
t0.5,2,1	12.706

t is less than t0.05

accept Ho

Regression Significance t test - 99%
Ho = no correlation

t =	5.678855
t0.01,2,1	63.65

t is less than t0.01

accept Ho

Legend	
X	hauling time (hours)
Y	reported dose
X2	X times X
Y2	Y times Y
XY	X times Y
n	number of points
sumX	sum of all X values
sumX2	sum of all X times X values
sumx2	equation D-3
sumY	sum of all Y values
sumY2	sum of all Y times Y values
sumXY	sum of all X times Y values
sumxy	equation D-7
b	slope of regression line
Xave	average value of X
Yave	average value of Y
intercept	intercept of regression line
totalSS	equation D-4
regSS	equation D-6
residual	totalSS minus regSS
sb	equation D-10
t	calc. t value equation D-9
t0.01,2,5	value from student t dist. (99%)
t0.05,2,5	value from student t dist. (95%)

Table D-3
Statistical Data Used to Develop the Correlation Shown on Figure 8-3

X	X2	Y	Y2	XY	
145	21025	0.2	0.04	29	Intercept
225	50625	0.3	0.09	67.5	r2
					No. of Observations (n)
					Degrees of Freedom (n-2)
					slope

n	2	deg.of.free	0
sumX	370		
sumX2	71650		
sumx2	3200	totalSS	0.005
sumY	0.5	regressSS	0.005
sumY2	0.13		
sumy2	0.005	Residual	ERR
sumXY	96.5		
sumxy	4	r2	1
		t0.5,2,1	12.706
b(slope)	0.00125		
Xave	185		
Yave	0.25		
intercept	0.01875		

Legend	
X	No. of waste containers hauled
Y	reported dose
X2	X times X
Y2	Y times Y
XY	X times Y
n	number of points
sumX	sum of all X values
sumX2	sum of all X times X values
sumx2	equation D-3
sumY	sum of all Y values
sumY2	sum of all Y times Y values
sumXY	sum of all X times Y values
sumxy	equation D-7
b	slope of regression line
Xave	average value of X
Yave	average value of Y
intercept	intercept of regression line
totalSS	equation D-4
regSS	equation D-6
residual	totalSS minus regSS
sb	equation D-10
t	calc. t value equation D-9
t0.01,2,5	value from student t dist. (99%)
t0.05,2,5	value from student t dist. (95%)

Table D-4

Statistical Data Used to Develop the Correlation Shown on Figure D-1

X	X2	Y	Y2	XY
1501	2253001	4.4	19.36	6604.4
1673	2798929	2.3	5.29	3847.9
42	1764	0.4	0.16	16.8
39	1521	0.1	0.01	3.9
960	921600	1.3	1.69	1248
838	702244	1.5	2.25	1257
1757	3087049	4	16	7028
1940	3763600	2.6	6.76	5044
1035	1071225	2	4	2070
878	770884	0.5	0.25	439
337	113569	0.3	0.09	101.1
100	10000	0.1	0.01	10
1220	1488400	2.8	7.84	3416
1070	1144900	0.4	0.16	428

Regression Summary Output:	
Intercept	-0.14028
r2	0.667212
No. of Observations (n)	14
Degrees of Freedom (n-2)	12
slope	0.001841

n	14	Deg.free	12
sumX	13390	totalSS	27.063571429
sumX2	18128686	regressSS	18.057164636
sumx2	5322107.	Residual	0.7505338992
		r2	0.6672129244
sumY	22.7		
sumY2	63.87		
sumy2	27.06357		
sumXY	31514.1		
sumxy	9803.171		
b(slope)	0.001841		
Xave	956.4285		
Yave	1.621428		
intercept	-0.14028		
sb	0.000375		

Regression Significance t test - 95%
Ho = no correlation
t 4.905006

t0.5,2,12 2.179
t is greater than t0.05
reject Ho

Regression Significance t test - 99%
Ho = no correlation
t 4.905006

t0.01,2,12 3.055
t is greater than t0.01
reject Ho

Legend	
X	total packages handled in 3 months
Y	reported dose
X2	X times X
Y2	Y times Y
XY	X times Y
n	number of points
sumX	sum of all X values
sumX2	sum of all X times X values
sumx2	equation D-3
sumY	sum of all Y values
sumY2	sum of all Y times Y values
sumXY	sum of all X times Y values
sumxy	equation D-7
b	slope of regression line
Xave	average value of X
Yave	average value of Y
intercept	intercept of regression line
totalSS	equation D-4
regSS	equation D-6
residual	totalSS minus regSS
sb	equation D-10
t	calc. t value equation D-9
t0.01,2,5	value from student t dist. (99%)
t0.05,2,5	value from student t dist. (95%)

Table D-5
Statistical Data Used to Develop the Correlation Shown on
Figure D-2

X	X2	Y	Y2	XY
81	6561	0.5	0.25	40.5
423	178929	0.4	0.16	169.2
1529	2337841	2.8	7.84	4281.2
1643	2699449	2.5	6.25	4107.5
2255	5085025	3.2	10.24	7216
2962	8773444	6.7	44.89	19845.4
3315	10989225	6.6	43.56	21879

Regression Summary Output:	
Intercept	-0.32272
r2	0.927264
No. of Observations (n)	7
Degrees of Freedom (n-2)	5
slope	0.002044

n	7	Deg.free	5
sumX	12208		
sumX2	30070474		
sumx2	8779722	totalSS	39.5771428
sumY	22.7	regressSS	36.6984854
sumY2	113.19		
sumy2	39.57714	Residual	0.57573148
sumXY	57538.8		
sumxy	17950	r2	0.92726464

b(slope)	0.002044
Xave	1744
Yave	3.242857
intercept	-0.32272
sb	0.000256

Regression Significance t test - 95%
Ho = no correlation

t	7.983881
t0.5,2,5	2.571

t is greater than t0.05

reject Ho

Regression Significance t test - 99%
Ho = no correlation

t	7.983881
t0.01,2,5	4.032

t is greater than t0.01

reject Ho

Legend

X	No. of Cat. II&III pack. handled in 6 Months
Y	reported dose
X2	X times X
Y2	Y times Y
XY	X times Y
n	number of points
sumX	sum of all X values
sumX2	sum of all X times X values
sumx2	equation D-3
sumY	sum of all Y values
sumY2	sum of all Y times Y values
sumXY	sum of all X times Y values
sumxy	equation D-7
b	slope of regression line
Xave	average value of X
Yave	average value of Y
intercept	intercept of regression line
totalSS	equation D-4
regSS	equation D-6
residual	totalSS minus regSS
sb	equation D-10
t	calc. t value equation D-9
t0.01,2,5	value from student t dist. (99%)
t0.05,2,5	value from student t dist. (95%)

Table D-6
Statistical Data Used to Develop the Correlation Shown on
Figure D-3A

X	X2	Y	Y2	XY
83	6889	0.5	0.25	41.5
261	68121	0.4	0.16	104.4
1214	1473796	2.8	7.84	3399.2
1294	1674436	2.5	6.25	3235
1774	3147076	3.2	10.24	5676.8
1813	3286969	6.7	44.89	12147.1
1920	3686400	6.6	43.56	12672

Regression Summary Output:	
Intercept	-0.36920
r2	0.777195
No. of Observations (n)	7
Degrees of Freedom (n-2)	5
slope	0.003024

n	7	Deg.free	5
sumX	8359		
sumX2	13343687		
sumx2	3361846.	totalSS	39.57714
sumY	22.7	regressSS	30.75919
sumY2	113.19		
sumy2	39.57714	Residual	1.763590
sumXY	37276		
sumxy	10168.95	r2	0.777195

b(slope)	0.003024
Xave	1194.142
Yave	3.242857
intercept	-0.36920
sb	0.000724

Regression Significance t test - 95%
Ho = no correlation
t 4.176270

t0.5,2,5 2.571

t is greater than t0.05

reject Ho

Regression Significance t test - 99%
Ho = no correlation
t 4.176270

t0.01,2,5 4.032

t is greater than t0.01

reject Ho

Legend	
X	No. weighted (typ.) packages handled in 6 months
Y	reported dose
X2	X times X
Y2	Y times Y
XY	X times Y
n	number of points
sumX	sum of all X values
sumX2	sum of all X times X values
sumx2	equation D-3
sumY	sum of all Y values
sumY2	sum of all Y times Y values
sumXY	sum of all X times Y values
sumxy	equation D-7
b	slope of regression line
Xave	average value of X
Yave	average value of Y
intercept	intercept of regression line
totalSS	equation D-4
regSS	equation D-6
residual	totalSS minus regSS
sb	equation D-10
t	calc. t value equation D-9
t0.01,2,5	value from student t dist. (99%)
t0.05,2,5	value from student t dist. (95%)

Table D-7
Statistical Data Used to Develop the Correlation Shown on
Figure D-3B

X	X2	Y	Y2	XY
347	120409	0.5	0.25	173.5
1025	1050625	0.4	0.16	410
4875	23765625	2.8	7.84	13650
5195	26988025	2.5	6.25	12987.5
7187	51652969	3.2	10.24	22998.4
7081	50140561	6.7	44.89	47442.7
7408	54878464	6.6	43.56	48892.8

Regression Summary Output:	
Intercept	-0.32600
r2	0.746343
No. of Observations (n)	7
Degrees of Freedom (n-2)	5
slope	0.000754

n	7	Deg.free	5
sumX	33118		
sumX2	2.1E+08		
sumx2	51910688	totalSS	39.57714
sumY	22.7	regressSS	29.53814
sumY2	113.19		
sumy2	39.57714	Residual	2.007798
sumXY	146554.9		
sumxy	39157.95	r2	0.746343

b(slope)	0.000754
Xave	4731.142
Yave	3.242857
intercept	-0.32600
sb	0.000196

Regression Significance t test - 95%
Ho = no correlation
t 3.835584

t0.5,2,5 2.571

t is greater than t0.05

reject Ho

Regression Significance t test - 99%
Ho = no correlation
t 3.835584

t0.01,2,5 4.032

t is less than t0.01

accept Ho

Legend

X	No. weighted (avg.) packages handled in 6 months
Y	reported dose
X2	X times X
Y2	Y times Y
XY	X times Y
n	number of points
sumX	sum of all X values
sumX2	sum of all X times X values
sumx2	equation D-3
sumY	sum of all Y values
sumY2	sum of all Y times Y values
sumXY	sum of all X times Y values
sumxy	equation D-7
b	slope of regression line
Xave	average value of X
Yave	average value of Y
intercept	intercept of regression line
totalSS	equation D-4
regSS	equation D-6
residual	totalSS minus regSS
sb	equation D-10
t	calc. t value equation D-9
t0.01,2,5	value from student t dist. (99%)
t0.05,2,5	value from student t dist. (95%)